Welding Process Using Special Torch for Reducing Diffusible Hydrogen

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Diffusible hydrogen is an important factor in cold cracking, and the lower its content, the better. This study contains a discussion and analysis of the behavior of hydrogen sources in metal active gas (MAG) welding consumables (hereinafter, "welding wires") to devise and develop a new process for reducing diffusible hydrogen, a process for suctioning and discharging the hydrogen sources desorbed from welding wires. Evaluation of the effectiveness of the new process has confirmed that it renders harmless the influence of surface lubricant and moisture absorbed after production and is effective as a new technique for reducing hydrogen. The subject welding wires include both solid wires and flux-cored wires (FCW). In the case of the latter, the moisture initially contained in the flux has been significantly reduced for seamed FCW: the effect, however, is less significant for seamless FCW. The present process has been found to be particularly effective when combined with seamed FCW.

Introduction

In various industries, many structures are becoming increasingly larger in size to meet the demand for higher efficiency. Accordingly, attempts are being made to increase the thickness and tensile strength of steel materials to ensure the strength and rigidity of the members. Such an attempt, however, can increase the cold cracking susceptibility of welding, making it difficult to manage welding works.

The factors causing cold cracking fall roughly into four major categories: (1) factors related to base metal (such as carbon equivalent), (2) factors related to hydrogen, (3) dynamic factors such as residual stress, and (4) the thermal history of welded portions.[1)]

Several technologies have been known to prevent cold cracking. With regard to the material technology, for example, thermo-mechanical controlled processed (TMCP) high-tensile steel, with suppressed hardening of the microstructure in the heat-affected zone, has been developed and is already in practical use. Other technologies often involve measures against diffusible hydrogen, and the most common technique is to perform preheating and/or postheating to increase the diffusion rate of hydrogen in the steel to facilitate its detachment from the base metal. Managing the heating involved in preheating and postheating, for example, requires a lot of labor and energy. Moreover, high temperatures can deteriorate the welding work environment, causing serious health and safety issues.

Hence, the focus is centered on the amount of diffusible hydrogen in weld metal. Its reduction can facilitate the management of heating, which is important as a measure for managing the welding work of large structures.

This study relates to the amount of diffusible hydrogen in the weld metals formed by gas metal arc welding (GMAW) and flux-cored arc welding (FCAW) and focuses on the occurrence and entry pathway of moisture and other hydrogen sources in welding wires, a subject area that has not been studied so far. The result has led to the devising of a new welding process for reducing the amount of diffusible hydrogen in weld metals. Furthermore, factors influencing the effectiveness of the process have been studied using an apparatus developed for the practical applications.

1. Past studies on welding methods for reducing diffusible hydrogen

A number of methods have been studied with the aim of reducing diffusible hydrogen in weld metals. Many of these studies are concerned with welding consumables, the oldest being a study on covered electrodes.[2)] The techniques of hydrogen reduction include technologies for the selection/processing of raw materials to lower the moisture content (hydrated minerals, etc.) in the covered flux and the designing of technologies to reduce the partial pressure of hydrogen in an arc atmosphere by employing a gas forming agent (containing no hydrogen). Regarding the hydrogen reduction technique for flux-cored wires, a production technology that involves wire annealing in the production process has been studied, and there is a report that the amount of diffusible hydrogen was decreased to a level of 0.5 ml/100 g.[3)]

Other than the field of welding consumables, a study was conducted on a welding method for reducing diffusible hydrogen using special shielding gas.[4)] Mixing CF_4 in shielding gas is reported to reduce the amount of diffusible hydrogen in weld metals. However, there are concerns about the safety of decomposed gas and a problem with deteriorated arc stability. Moreover, CF_4 is a greenhouse gas, and its use is restricted. Thus, there are many problems to be solved before it can be applied.

As described above, research has been conducted on various aspects of the issue to reduce the amount of diffusible hydrogen in weld metals. However, there seem to be no examples of this issue being approached from the aspect of the welding apparatus.

2. Design of process for reducing diffusible hydrogen using special torch

It is obvious that a hydrogen source migrates from a welding consumable to the weld metal via the welding process; however, it is not necessarily clear what route it takes. Hence, the following conjecture has been made:

During welding, the wire between the contact tip and base metal is heated by the Joule heat and arc heat due to the welding current. If a sufficiently high temperature is reached at this time, the hydrogen source is considered to be desorbed from the wire due to thermal energy.[5)] The desorbed gas is carried by the peripheral flow of the shielding gas and transported to the droplet and/or arc generating area. Eventually, it reaches the molten pool, in which hydrogen dissolves into the weld metal. If this conjecture is correct, the amount of hydrogen absorbed into the weld metal should be decreased by somehow discharging from the welding system the hydrogen sources desorbed from the wire along with the surrounding gas, thus decreasing the amount of hydrogen that comes in contact with the droplet and/or molten pool. Hence, a special welding torch has been devised to confirm whether this idea is practical. **Fig. 1** schematically illustrates the special torch. This torch constitutes a double-nozzle torch system comprising an additional nozzle (called a suction nozzle) provided between the contact tip and the shielding nozzle. The negative pressure generated in the space inside the suction nozzle allows the suction of gas near the wire during gas-shielded arc welding.

3. Mechanism of process for reducing diffusible hydrogen and structural design of special torch

In order to verify the effectiveness of the process concept of reducing diffusible hydrogen by using a special torch, and to optimize the structural design of the torch, the temperature of a wire has been calculated and confirmed by an experiment. The subject welding wire is a flux-cored wire, which contains a larger number of hydrogen sources than a solid wire.

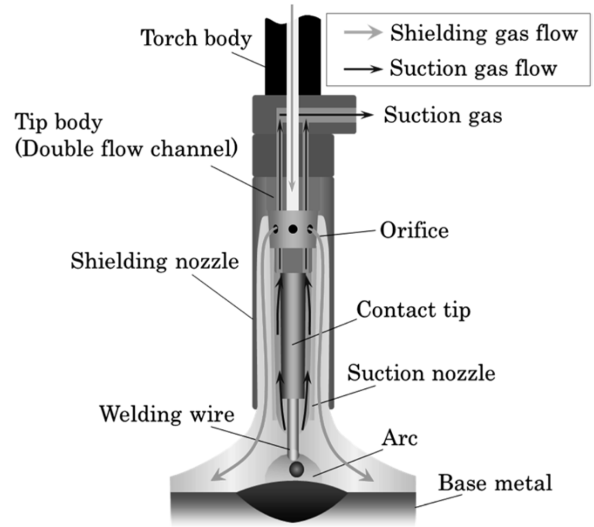


Fig. 1 Schematic illustration of special welding torch

3.1 Estimating temperature distribution of wire during welding

3.1.1 Calculation technique

To verify the hypothesis of hydrogen sources being desorbed due to the temperature rise of the wire during welding, and to optimize the suction position of the gas surrounding the wire (the amount that the suction nozzle protrudes in the longitudinal direction), the temperature distribution of the wire after being fed from contact tip has been estimated.[6)] The calculation has been based on a model simplified as follows:

(A) It is assumed that the wire is heated only by Joule heat: i.e., heat transfer, radiant heat of arc, etc., are not taken into account.

(B) It is assumed that the time it takes for the wire protruding from the contact tip to reach the arc region is small enough for thermal conduction to be ignored.

(C) The Joule heat taken into account is as follows:
① Heat due to the contact resistance between the contact tip and wire, and
② Heat due to the resistance of the welding wire itself.

(D) For simplicity, the power is assumed to be supplied only from the pointed end of the contact tip, and as for ①, "heat due to the contact resistance," 50% of the heat generated is regarded as the heat input into the wire.

Shimizu et al. have reported that the influence on the temperature rise in wires due to the shunt within the contact tip is small for solid wires without copper plating.[7] It should be noted that the flux-cored wire that is the object of this calculation is without copper plating. Furthermore, the calculation in this report assumes that 50% of the amount of heat generated by contact resistance is input into the wire; hence, assumption (D) is deemed valid.

On the basis of the above assumptions and assuming the contact tip to be the origin of coordinates, the temperature distribution between the tip and arc is expressed by Equation (1). The second term on the right side indicates the temperature rise due to ① and the third term indicates that due to ②.

$$T(x)=T(0)+\frac{0.5R_c(I)I^2}{mv_w c(T(0))}+\int_0^x \frac{R_w(T)I^2}{mv_w c(T)}dx \quad \cdots\cdots\cdots (1)$$

where

T : wire temperature [℃]
x : distance in the wire axis direction from the contact tip [m]
I : welding current [A]
R_c : contact resistance of wire without copper plating [Ω]
m : wire mass per unit length [g/m]
v_w : feed rate of wire [m/s]
c : specific heat of iron[8] [J/gK]
R_w : electrical resistance of wire per unit length [Ω/m].

With regard to the physical properties used for the calculation, the electrical resistance of the wire, R_w, was obtained through the actual measurement of the temperature characteristics in which a flux-cored wire of ϕ1.2 mm was heated with a constant-current power to measure the voltage drop and temperature of the wire with a fixed length.

The contact resistance of the wire without copper plating, R_c, has been calculated by Equation (2):[7]

$$R_c=1.2\times10^{-2}-6.0\times10^{-5}I+1.0\times10^{-7}I^2 \cdots\cdots\cdots\cdots (2)$$

3.1.2 Calculation results

Fig. 2 shows the result of the calculation based on Equation (1) using respective physical properties. The calculation assumes a contact tip-to-work distance of 25 mm; the electric current and wire feed rate, each at two levels of experimental values, have been set to 210A-10.3 m/min and 270A-15.1 m/min, respectively. The wire mass has been set to 6.98 g/m on the basis of the actual measurement. Although there are some differences depending on the electric current, the calculation results show that, in either case, the welding wire reaches 500℃ at a position approximately 11 mm from the contact tip and the temperature rises to 1000℃ at approximately 20 mm immediately in front of the arc.

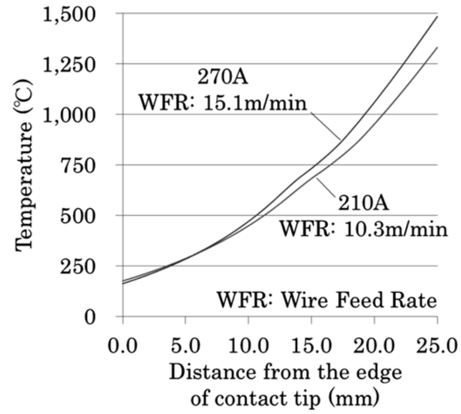


Fig. 2 Calculation results of temperature distribution on welding wire

3.2 Relationship between welding wire temperature and amount of desorbed gas

3.2.1 Tested material and experimental method

The flux-cored wire was subjected to the desorbed gas analysis under elevating temperature (thermal desorption spectroscopy) to confirm the temperature characteristics of the desorption behavior of hydrogen source when the wire has been heated between the contact tip and the base metal.[6] The thermal desorption spectroscopy (hereinafter referred to as "TDS") is a technique of heating a sample to raise its temperature in a vacuum container and analyzing the gas desorbed from the sample at each temperature during the heating. The desorbed gas collides with accelerated electrons to be ionized and is separately identified for each mass-to-charge ratio (m/z). The analysis results are obtained as ion electric current, and its magnitude correlates with the desorption amount of the molecule of interest.

In this study, TDS was applied to the flux-cored wire, and the desorption temperature characteristics of water (H_2O: molecular weight, 18) were measured. The heating rate during the analysis was 10℃/min. If the desorption of organic substances and oil could be measured, more accurate behavior would have been obtained. However, the molecular weight of decomposed gas is unknown, and the ion currents, which are the analysis result of the TDS, cannot be used for the absolute comparison of different substances. Hence, this analysis focuses only on water.

Table 1 shows a list of the materials tested. In each case, a prototype seamed flux-cored wire of ϕ1.2 mm, corresponding to JIS Z 3313 T49J0T1-1,

Table 1 Samples of FCW for TDS

Sample No.	Wire	Applicable standard	Wire diameter (mm)
A	Flux cored wire A	JIS Z 3313 T49J0T1-1 (AWS A5.20 E71T-1C)	1.2
B	Flux cored wire B		
C	Flux cored wire C		

has been selected. For TDS, continuous wires were used, each adjusted to 1.00 g (approximately 140 mm).

3.2.2 Experimental results

The TDS analysis results are shown in **Fig. 3**. Each sample exhibits a major peak at around 100℃, and subsequently, the desorption amount decreases with increasing temperature. It is shown that the desorption of water is almost completed in the temperature range not exceeding 500℃.

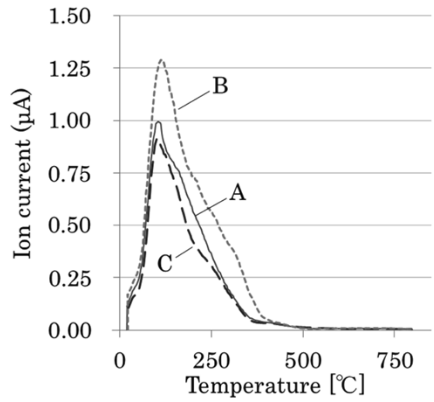


Fig. 3 Analysis results of TDS (H_2O)

3.3 Design of special torch

The results of the calculation in Section 3.1 show that the temperature of the wire reaches 500℃ at a position about 11 mm from the contact tip when the distance between the contact tip and the base metal is 25 mm. Moreover, the results of TDS in Section 3.2 have confirmed that, in the case of the seamed flux-cored wire, the desorption of the moisture contained in the wire is completed before the temperature reaches 500℃.

The above results indicate that, in order to prevent the droplet and molten pool from contacting the hydrogen sources discharged outside the welding wire by evaporation and/or decomposition, it is important to suction the atmospheric gas in the peripheral area of the wire up to a position about 11 mm away from the contact tip. In view of the above, the special torch used for the process of reducing diffusible hydrogen has been designed such that a suction nozzle wraps around the 12 mm portion of the wire protruding from the contact tip (**Fig. 4**). It should be noted that the heating rate of the wire during welding and the heating rate of TDS are significantly different. Therefore, the actual welding may not exhibit a behavior similar to the one exhibited during the TDS, and experimental verification is required.

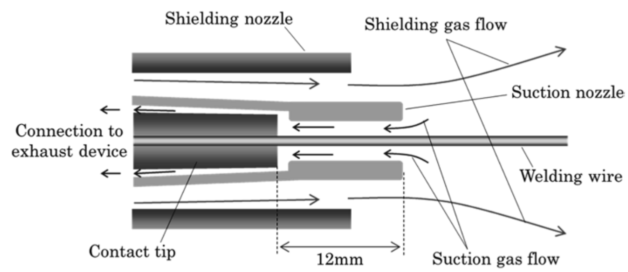


Fig. 4 Structure and dimension of developed welding torch (Longitudinal section)

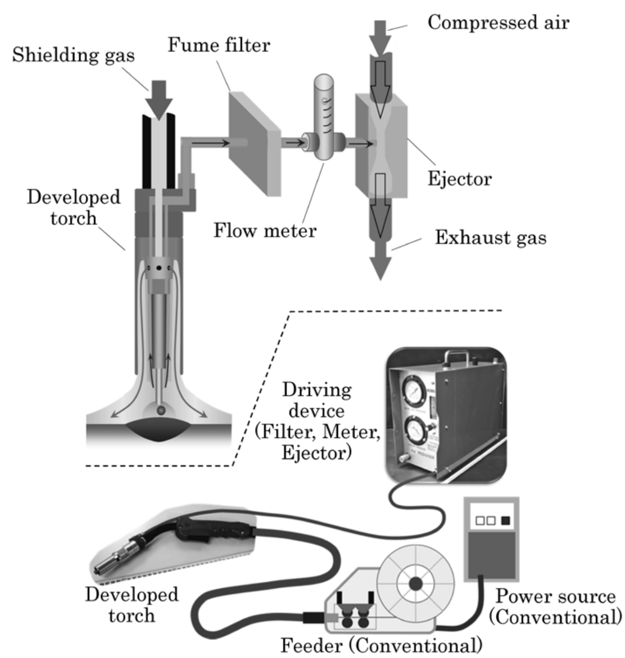


Fig. 5 Prototype torch system

On the other hand, the negative pressure is designed to be generated by a mechanism using an ejector. An ejector is a device that can generate negative pressure by the venturi effect, and small general-purpose devices are easily available. Manufacturing plants where welding is performed usually have pipes of compressed air. Hence, there is no problem in obtaining compressed air, which is advantageous in that the downsizing and simplification of the apparatus are easier than in the cases where pumps are used. A flow meter has also been installed to control the flow of suction gas. In addition, a filter has been installed to protect the flow meter from welding fume (smoke of fine metal). **Fig. 5** shows the schematic diagram and appearance of the prototype torch system.

4. Confirmation of effects of special torch developed and influence, on the effects, of factors related to welding wires[5), 6)]

The newly developed special torch has been used to confirm the effectiveness of the process for reducing diffusible hydrogen.[6)] The sources of diffusible hydrogen contained in the welding wire are classified as shown in **Table 2**.[5)] It has been envisaged that the influence of reducing the amount of diffusible hydrogen depends on these hydrogen sources. Hence, each factor has been verified independently.

4.1 Testing materials and experimental method

4.1.1 Material for testing effectiveness against surface lubricant

Welding wires usually have a surface lubricant applied on their surfaces to secure feedability and prevent the surfaces from rusting. Most lubricants are organic and, therefore, become a hydrogen source. In order to independently confirm the influence of "(a) surface lubricant," which is one of the factors affecting the amount of diffusible hydrogen, prototype solid wires have been prepared with different amounts of lubricant on their surfaces. In the case of solid wires, the influence of factors (b) and (c) is considered to be negligible.

The solid wires used for the test were first subjected to alkaline degreasing. After the degreasing, lubrication oil was applied under various coating conditions so that the wires have different amounts of adhering surface lubricant. **Table 3** shows the list of the wires prepared. The "amount of oil on surface" in the table was determined as follows:

① Sampling a certain amount of wire.
② Measuring the mass to determine w_1.
③ Degreasing with acetone, followed by drying.
④ Remeasuring the mass to determine w_2.
⑤ Calculating the amount of surface oil, A_{sl}, by Equation (3).

$$A_{sl} = \frac{w_1 - w_2}{w_1} \quad \cdots\cdots (3)$$

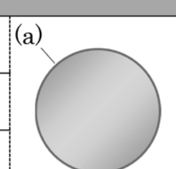
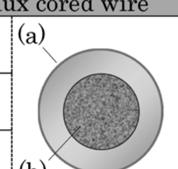
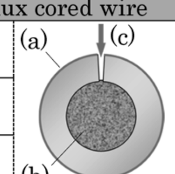
4.1.2 Material for testing effectiveness against initial content of moisture in flux

Since flux contained in flux-cored wires is in the form of powder with a large surface area, the adsorption of atmospheric moisture is inevitable, and its complete removal is impossible. For this reason, flux with some amount of moisture is supplied inside welding wires during their production. This moisture becomes a source of diffusible hydrogen.

Prototype flux-cored wires have been made to independently confirm the influence of "(b) the initial moisture content of flux," which is a factor influencing the amount of diffusible hydrogen. Prototype fluxes with a fixed composition have been prepared under different pretreatment conditions such that they have differing moisture content. The term "pretreatment" as herein used includes the presence or absence of material baking, baking conditions, and pulverization methods, such as wet pulverization and dry pulverization.

These fluxes have been used to make flux-cored

Table 2 Welding-wire-related factors affecting the diffusible hydrogen in GMAW and FCAW

Factors of hydrogen source	Solid wire		Seamless flux cored wire		Seamed flux cored wire	
(a) Surface lubricant	○		○		○	
(b) Initial moisture of flux	-		○		○	
(c) Moisture absorbed after production	-		-		○	

Note ○: Applicable, -: Negligible

Table 3 Trial solid wires for testing the effectiveness of developed welding torch on surface lubricant

Sample No.	Amount of oil on surface (ppm)	Applicable standard	Wire diameter (mm)
a1	0	JIS Z 3312 YGW11 (AWS A5.18 ER70S-G)	1.2
a2	60		
a3	110		
a4	540		

wires, some seamless and others seamed. The amount of surface lubricant has been controlled at low levels (in the range of sample a2 to a3 in Table 3). This is considered to render the effect of factor (a) negligible (reference made to 4.2.1) and, in the case of seamless flux-cored wires, renders the effect of factor (c) negligible. In the case of seamed flux-cored wires, attention has been paid to minimize the influence of factor (c), e.g., storage after production in a low humidity atmosphere. **Table 4** shows the list of wires prepared. The values of "Moisture content of flux" in the table have been measured by Karl Fischer titration (carrier gas, Ar; extraction temperature, 750℃).

4.1.3 Test material for confirming influence of moisture absorbed after production

It is thought that, if unsealed, seamed flux-cored wires absorb moisture from the atmosphere over time. Hence, prototype seamed flux-cored wires have been made to independently confirm the influence of factor (c), "moisture absorbed after production," on the amount of diffusible hydrogen. Each sample has been dried in a constant temperature furnace at 80℃ for 3 hours and subsequently moisturized in a thermo-hygrostat at 30℃, 80%RH for a varying time before the amount of diffusible hydrogen has been measured. In this experiment as well, the amount of surface lubricant has been controlled at low levels (in the range of samples a2 to a3 in Table 3), and the influence of factor (a) is considered to be negligible. Moreover, the influence of factor (b) is considered to be sufficiently small, since drying and moisture absorption have been performed after splitting continuous wires. No experiment has been conducted on seamless flux-cored wires, since they are not considered to absorb moisture. Furthermore, this experiment used three-types of flux-cored wires with different applicable standards. The differences are due to the design of the flux compositions. **Table 5** shows a list of sample wires.

The newly developed torch was applied to the prototype wire to be subjected to the mass measurement of diffusible hydrogen. At this time, the flow rate of suction gas was set to 5l/min. A conventional welding torch was also tested to clarify the effectiveness of the process for reducing diffusible hydrogen. Gas chromatography was used for measuring under the conditions of JIS Z 3118, except for the contact-tip-to-work distance. To comply with JIS Z 3118 strictly, the contact-tip-to-work distance should be 20 mm for solid wires; however, the distance was set to 25 mm in this test to be consistent with the tests for flux-cored wires. **Table 6** shows the welding conditions during the sample preparation.

Table 4 Trial FCW for testing the effectiveness of developed welding torch on initial moisture of flux

Sample No.	Seam type	Moisture content of flux (ppm)	Applicable standard	Wire diameter (mm)
b1	Seamless	350	JIS Z 3313 T49J0T1-1 (AWS A5.20 E71T-1C)	1.2
b2		1210		
b3	Seamed	350		
b4		1210		

Table 5 Trial seamed FCW for testing the effectiveness of developed welding torch on moisture absorbed after production

Sample No.	Applicable standard	Strength class	Moisture absorption time (hr)	Wire diameter (mm)
c1-1	JIS Z 3313 T49J0T1-1	490 MPa	0	1.2
c1-2			24	
c1-3			288	
c2-1	JIS Z 3313 T556T1-1	550 MPa	0	
c2-2			24	
c2-3			72	
c2-4			232	
c3-1	AWS A5.29 E81T1-K2C	550MPa	0	
c3-2			24	
c3-3			72	
c3-4			232	

Table 6 Welding conditions

Welding current (A)	Arc voltage	Welding speed (mm/min)	Contact tip-to-work distance (mm)	Shielding gas	
				Composition	Flow rate (l/min)
300 (Solid) 270 (FCW)	Appropriate	350	25	CO_2	25

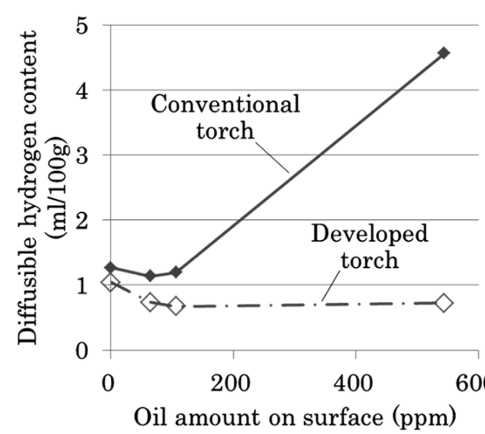


Fig. 6 Effectiveness of developed welding torch on surface lubricant

4.2 Experimental results

4.2.1 Effectiveness against surface lubricant

Fig. 6 shows the amounts of diffusible hydrogen measured on the sample wires shown in Table 3 along with the results for the conventional welding torch. The newly developed torch appears to be highly effective against factor (a), rendering it harmless. In the range where the amount of surface oil is 110ppm or less (samples Nos. a1 to a3 in Table 3), the plots for the newly developed torch are inclined downward to the right. This is considered to be due to measurement errors, and the amount of diffusible hydrogen is regarded as almost constant.

In the case of the conventional welding torch, no significant difference was found in the amount of diffusible hydrogen when the amount of surface oil was 110ppm or less (a1 to a3), and it was found that trace amounts of lubricant had no significant influence.

4.2.2 Effectiveness against initial moisture content of flux

Fig. 7 shows the amounts of diffusible hydrogen measured on the sample wires shown in Table 4 along with the results for the conventional welding torch.

The results of the conventional welding torch will be described first. The seamless flux-cored wire exhibits a large difference in the range of fluctuation for the amount of diffusible hydrogen (circle, solid line), which is due to the initial content of moisture in the flux. On the other hand, the fluctuation range (square, solid line) is relatively small for the seamed flux-cored wire. When the initial content of moisture in the flux is low, the resulting amount of hydrogen becomes higher than that in the seamless wire. Conversely, higher moisture content resulted in a hydrogen amount lower than that of the seamless wire.

Next, the results for the conventional welding torch were compared with those for the newly developed torch (circle, broken line) for the seamless flux-cored wire. The newly developed torch had a minor effect on the reduction of diffusible-hydrogen, as low as 0.5 to 1 ml/100 g. In other words, the reduction effect on the initial moisture content of factor (b) is regarded as small. In the case of the seamed flux-cored wire, on the other hand, the newly developed torch (square, broken line) had a remarkable effect on the reduction of diffusible hydrogen, as much as 3 to 4 ml/100 g. In other words, it is possible to render most initial moisture harmless by using the newly developed torch.

4.2.3 Effectiveness against moisture absorbed after production

Fig. 8 shows the amounts of diffusible hydrogen measured on the wires shown in Table 5 along with the results for the conventional welding torch. In the case of the conventional welding torch, the diffusible hydrogen content tends to increase with the elapsed time of moisture absorption. In the case of the newly developed torch, on the other hand, no such tendency has been observed, and even after the moisture absorption time has elapsed, the diffusible hydrogen content remains almost constant. The moisture absorbed after production is considered to consist mainly of adhering water, which can easily be detached, and it is considered that the newly developed torch works very effectively to reduce diffusible hydrogen.

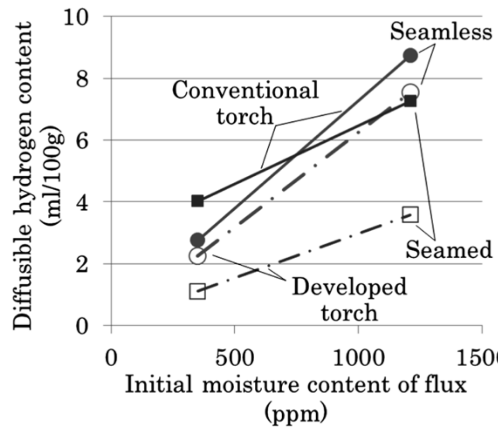


Fig. 7 Effectiveness of developed welding torch on initial moisture of flux

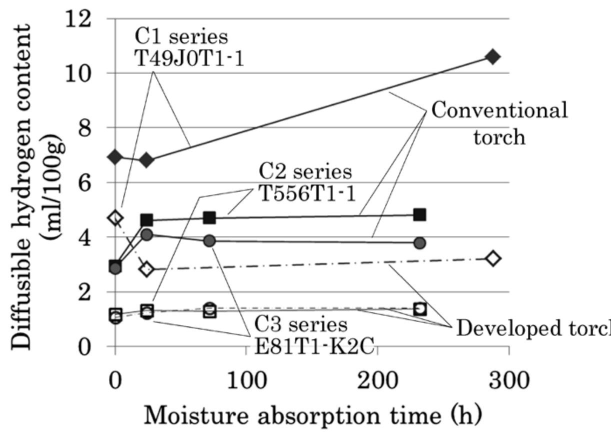


Fig. 8 Effectiveness of developed welding torch on moisture absorbed after production

4.3 Discussion

To confirm the mechanism resulting in the difference in reduction behaviors of diffusible hydrogen in seamed and seamless wires, as described in 4.2.2, TDS tests have been conducted in addition to the ones performed in 3.2.

Two types of wires, seamed flux-cored wire A and a seamless flux-cored wire D, were tested. The seamed flux-cored wire A is as shown in Table 1. The seamless wire D is also a prototype wire of ϕ1.2 mm corresponding to JIS Z 3313 T49J0T1-1 and is similar to A. The wire moisture contents measured by Karl Fischer titration (carrier gas, Ar; extraction temperature, 750℃) are 373 ppm for wire A and 48ppm for wire D.

The sample was adjusted to 1.00 g as described in Section 3.2.1. In addition, in order to evaluate the influence of the wire seam, both seamless and seamed flux-cored wires were sealed by TIG welding at both ends to prevent any disturbance from occurring. The TIG welding at each end was performed by sandwiching with grooved copper plates so that the 10 mm wire end was exposed. The exposed part was put into the TIG arc. **Table 7** lists the samples, and **Fig. 9** shows the results.

Table 7 TDS samples in order to confirm the effect of wire seam

Sample No.	Wire	Wire end sealing
A1	Seamed flux cored wire A	Not applied
A2		Applied
D1	Seamless flux cored wire B	Not applied
D2		Applied

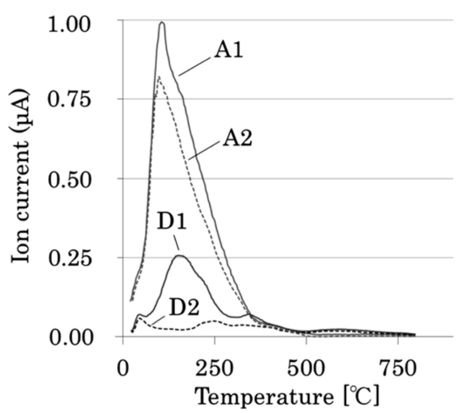


Fig. 9 Analysis results of TDS (H_2O)

A comparison of samples A1 and D1 shows that their main peak appears in the same temperature region, although there is a difference in the amount of water desorbed due to the difference in moisture content. A comparison between samples A1 and A2 shows that the peak height of A2 was decreasing. This is considered to be due to the fact that A2 is fused at each end by the TIG welding in the preliminary treatment.

Comparing D1 and D2, on the other hand, indicates that the peak appearing for D1 disappears for D2. This indicates that, in the case of the seamless wire with both ends sealed, the moisture in the flux continues to be held without being desorbed outside the wire even at a high temperature of 800℃, the upper limit temperature of this test. This result suggests that the moisture and other hydrogen sources inside seamless wires will not be discharged outside the wires even under the influence of Joule heat during welding.

In other words, in the case of the hydrogen reduction process that uses the newly developed torch, the difference in the behavior of diffusible hydrogen reduction due to the presence/absence of a seam can be understood as follows: The seamless flux-cored wire has a sealed structure and, when the wire is Joule-heated between the contact tip and base metal, it cannot release the hydrogen source contained inside, rendering the use of the nozzle to suction gas ineffective. In the case of seamed flux-cored wires, on the other hand, the hydrogen source is easily desorbed outside the wire through the seam and suctioned by the nozzle. As a result, the hydrogen partial pressure in the arc drops efficiently, greatly reducing the diffusible hydrogen. The above difference in behaviors is schematically shown in **Fig. 10**.

It is difficult to directly observe how the moisture

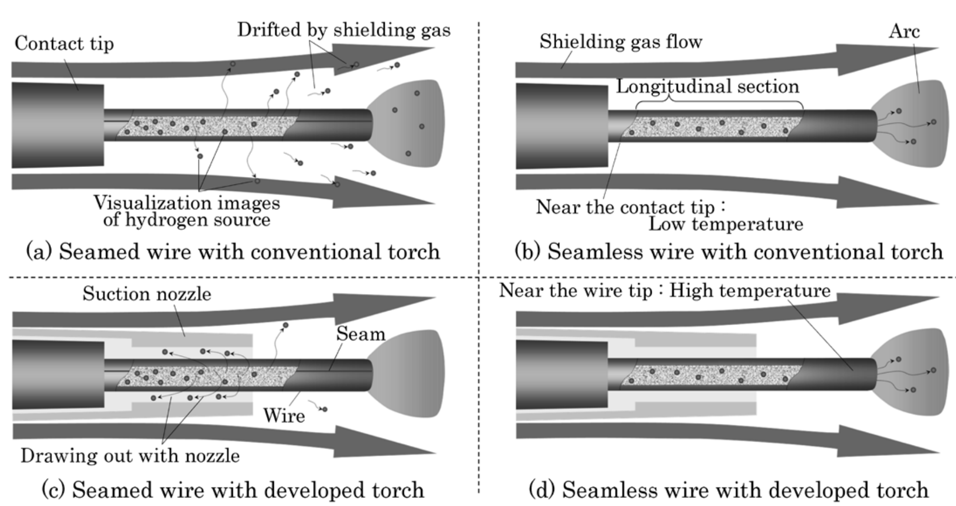


Fig.10 Schematic illustrations of the behavior of moisture in FCW during welding

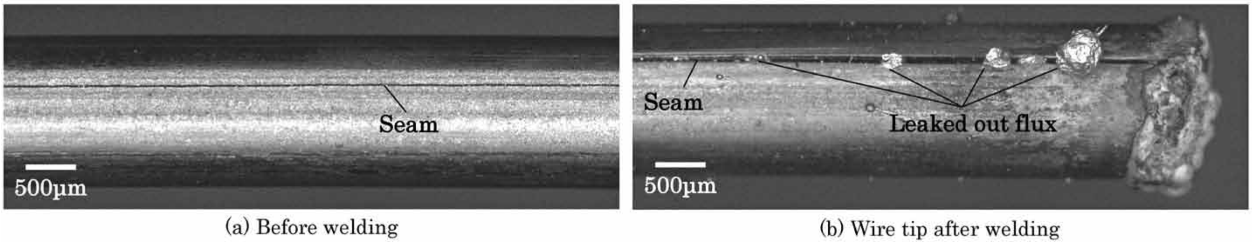


Fig.11 Comparison of wire surface appearance

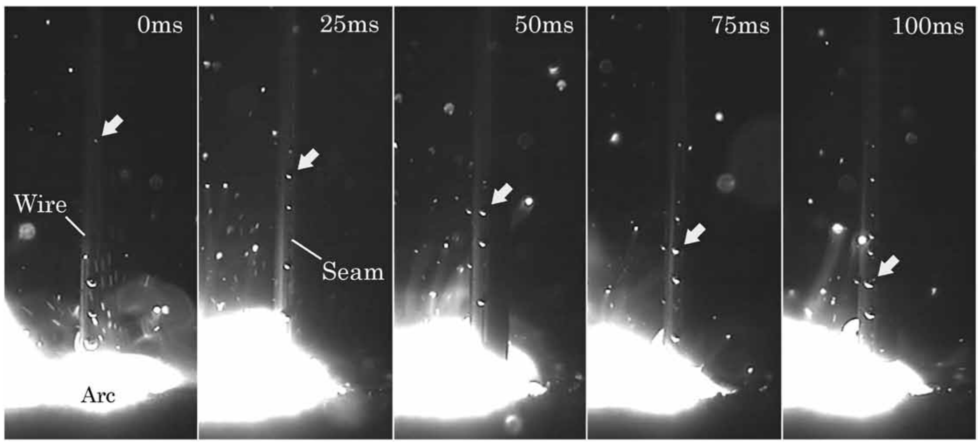


Fig.12 High-speed-video observation result of wire extension part of FCAW

is evaporated and discharged from a seam during welding. There are, however, cases where flux that cannot normally be visually confirmed can be seen leaking from the seam after welding (**Fig. 11**).[5] The wire under observation is a wire of ϕ 1.6 mm conforming to AWS A5.20 E71T-14. The wire extension of the same type of wire has been subjected to high-speed imaging during welding as shown in **Fig. 12**. The arrow in the figure indicates the same droplet descending with the time elapsed. The photos show how a flux-derived droplet that cannot be confirmed by appearance at the top of the image, further from the arc, seeps out from the seam and grows into a larger droplet as it approaches the arc-generating area. The internal pressure of the wire is undoubtedly increased with rising temperature, and it is reasonable to conclude from the above phenomenon that the increased pressure has discharged the moisture from the wire.

5. Possibility of process for reducing diffusible hydrogen

A newly developed special torch that suctions gas near the welding wire has been used to describe the effectiveness of the welding process for reducing the amount of diffusible hydrogen against various welding-wire related factors affecting the amount of diffusible hydrogen. The results obtained so far are summarized in **Table 8**.

Table 8 Summary of the effectiveness of developed welding torch

Factors of hydrogen source	Solid wire	Seamless flux cored wire	Seamed flux cored wire
(a) Surface lubricant	Total decrease	Total decrease	Total decrease
(b) Initial moisture of flux	-	Slight decrease	Great decrease
(c) Absorbed moisture after production	-	-	Total decrease

The process using the newly developed torch works very effectively against factor (a) and factor (c), rendering these factors harmless. For factor (b), no sufficient effect has been obtained in the case of seamless flux-cored wire. In the case of seamed flux-cored wire, the influence of the initial moisture content of the flux was greatly reduced. This, therefore, verifies the validity of the design reflecting the estimation of the wire temperature distribution during welding and that of the knowledge obtained from the desorption behavior analysis of the hydrogen source.

As described above, it has been shown that the combination of the newly developed torch and seamed flux-cored wire enables welding while rendering harmless many of the sources of diffusible hydrogen arising from welding consumables. In general, the diffusible hydrogen content in weld metal caused by the welding wire must be left to the manufacturers of welding consumables. However, by combining the newly developed torch with seamed flux-cored wires, it is possible that a user can dominantly control diffusible hydrogen, and the applicability of such a combination is expected to expand. For the manufacturers of welding consumables, there as the possibility that the degree of freedom for flux design will increase, enabling the development of consumables that can produce weld metal with high mechanical performance, less spatter generation, and favorable usability on position welding for thick, high-tensile steel plates.

It should be noted that this technique can also render harmless the influence of surface lubricant in solid wires and seamless flux-cored wires, which can be an effective means for reducing hydrogen.

Conclusions

① A process for reducing diffusible hydrogen has been developed using a special torch that enables welding work to be performed with the suction of gas near wires. ② The temperature distribution of a wire during welding and the results of the analysis of the behavior of hydrogen desorption from the wire have been reflected in the structure design of the special torch. Experimental results have verified the validity of the design. ③ Although the newly developed torch can achieve the reduction of diffusible hydrogen regardless of the type of wire, it is particularly effective for seamed flux-cored wires. ④ It has been confirmed that the sources of diffusible hydrogen in a wire are desorbed from inside or from the surface as the temperature between the contact tip and the melt/arc generation point rises, transported by shielding gas, and enter into the droplet and molten pool.

We will continue our efforts to demonstrate the possibility of applying this process to reduce the construction management (thermal management) of large structures. It is expected that this process can provide a solution in the field of welding work where thermal management seems to be causing problems.

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