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Materials Sensitive Phenomena in Gas-shielded Arc Welding Process†

— A State-of-the-art Review in Japan —

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Abstract

Effects of a very small amount of chemical elements which are contained in welding wire, base metal and shielding gas, on the welding Phenomena of gas-shielded arc welding are examined and related studies are reviewed in the past decade in Japan.

KEY WORDS : (Gas-shielded arc welding) (Minor element effect) (Welding process) (Wire composition) (Shield gas)

1. Introduction

A very small amount of chemical elements which are contained in welding wire, base metal and shield gas exert some influence upon the Gas-shielded Arc Welding phenomena.

In recent years, the addition of trace elements (minor elements) and its adjusting are being studied extensively so as to not only to improve the properties of weld metal, but also to improve the welding operation. Especially, by introducing an inverter controlling system to the welding power source, the controllability of welding has been practically improved. Under this situation, it should be essential to consider that sophisticated chemical compositions containing in the welding materials and shield gases can further improve the welding process.

In Japan, the study report concerning Gas-shielded Arc Welding technology from the point above mentioned is available though not so many. Actually about 30 reports have been presented in the Annual Meeting of Japan Welding Society during the past 1980 ~ 1989.

In these studies of GMA welding process, the effects of wire, shield gas and base metal compositions upon the welding penetration, spattering, weld metal properties are being picked up. Then among such studies, several studies have been clearly directed to the development of welding wire.

In addition, in the field of TIG (GTA) welding study, the behavior of oxides contained in tungsten electrode, TIG welding at high-pressure gas atmosphere, and the influence of shield gas composition upon gas absorption in weld metal have been selected as study subjects.

In 1981, the current reports of the above at that time in Japan were presented by N. Yamauchi and K. Agusa[1]. This paper is the continuation of their study reports, and reviews centering around the period after 1980 and up to now.

(I) GMA Welding

(A) Influence of Minor elements in welding wire

The purpose of addition of minor elements to welding wire is as follows :

- ○ Stabilization of weld arc and metal transfer
- ○ Suppression of spatter and blow hole
- ○ Reduction of oxygen contained in weld metal
- ○ Reduction of fume generation

A-1) Wire melting rate

A study of influence of arc stabilizing elements upon wire melting rate is being made by using recently developed flux cored wire including metal cored wire[2].

As a result, in DC welding process in electrode positive polarity, the wire melting rate is, as the same case as solid wire, expressed as follows :

$$M_R = \frac{1}{4.2\,\rho\,(H_0 + b)}\,(\phi j + aLj^2) \qquad (1)$$

where,
M_R : Wire melting rate
H_o : Heat content of droplet
L : Wire extension
a, b : Constant
ρ : Specific weight
j : Curent density
ϕ : Work function of wire material

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That is, the wire melting rate is expressed in the above equation[3]. In the flux cored wire, apparently the arc stabilizer which is contained in the flux affects to the wire melting rate, but only through the arc stabilization. The effect of arc stabilizer on wire melting rate of flux cored wire (includes metal cored wire) was examined in the electrode positive with 100% CO_2 and 80% Ar + 20% CO_2 shield gases. However, the influence is a little[4].

It is known that the addition of active elements to the solid wire can stabilize, even if the amount is very small, the arc, and consequently the arc length. According to the result, thus obtained, the active elements have effects upon the shortcircuiting periodicity and the size of molten droplet rather than upon the wire melting rate. That is to say, fundamentally, it is only effective upon the stabilization of arc, and it can be considered that there is practically no effect of active elements upon the wire melting rate.

However, in the case of electrode negative polarity, actually, arc root is formed on the wire, and the arc properties are strongly depending upon the existence of active element. This means that arc input heat amount varies possibly, and as a result, the tendency of the slight decrease in wire melting rate is observed. Actually, the study is being made on the Ca, Mg and REM additive wire[5].

A-2) Wire activation and stabilization of molten droplet transfer.

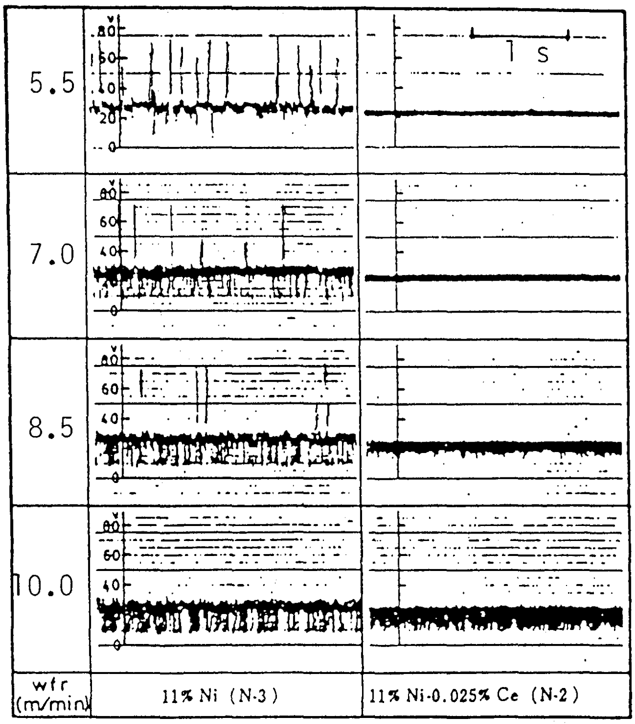

Fig. 1 Effect of Ce addition in wire on welding current[1)]

In the case of electrode positive, under the ambient atmosphere of 80% Ar + 20% CO_2 or 100% CO_2, the addition of REM to solid wire has no remarkable improvement. However, MIG welding under the inert gas atmosphere of Ar or Ar-He, regardless of polarity, as well as DC or AC, it is reported that the addition of REM contributes much upon the stabilization of arc[6]. The REM used here is mainly of Ce., and substantially used for the welding wire of high-Ni steel alloy and Cr-Mo steel alloy, through which excellent stability is obtainable.[7]

In the MIG welding with REM additive solid wire, the stabilization of arc and the spray transfer is realized in the electrode positive polarity. However, in electrode negative, stabilized projected transfer is feasible. Furthermore, in the AC welding, the reignition voltage is low. When the electrode negative polarity is used, the size of molten droplet would decrease in comparison with that of the no REM addition. This would be an interesting phenomenon.

A-3) Decrease in spatter generation

The study of CO_2 welding spatter by using solid wire containing minor elements has been made extensively for a considerably long period of time. According to the recent study report, as shown in **Fig. 2**, it has been cleared that the increase of Si, Ti and Mn elements in the solid wire, and the decrease of C and Al elements have the effect upon the reduction of welding spatter, respectively.

In fact, those types of solid wire can reduce the generation of welding spatter, down to 1/5 of the conventional types of welding wire[8].

According to the recent study of spatter by using an inverter CO_2 welding machine operated under the current-waveform control, it is reported that solid wire

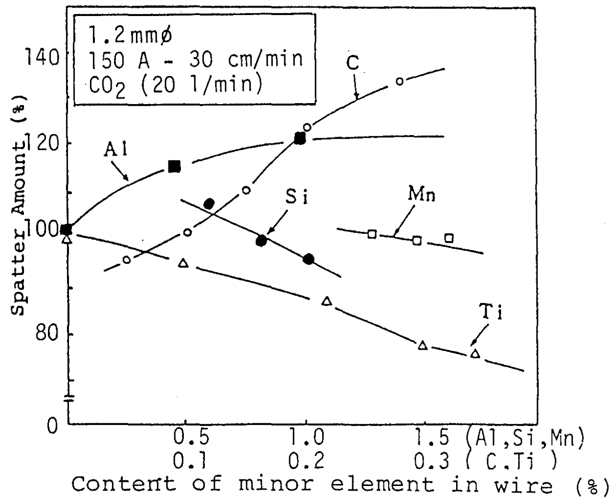

Fig. 2 Effect of minor element addition in wire on spatter[8)]

containing the minor elements of Ti and Al is effective to suppress spatter generation[9]. The results of study are shown in **Fig. 3** and **4.**

When the REM is added, it is clear that the shortcircuiting decreases actually. However, this is not always effective for the decrease of spatter because molten droplets grow large.

A-4) Formation of blow hole

In order to suppress the generation of blow hole, solid wire containing Al, Ti, Zr, and REM minor elements respectively was prepared for the test, through which miscellaneous examinations have been conducted. Welding of first layer of V-grooved mild steel was made under the ambient atmosphere of 80% Ar + 20% CO_2 so as to observe the blow hole generation frequency[10]. According to the test results, it has been cleared that the inclusion of REM, Al and Zr minor elements increase the occurrence of blow holes and the inclusion of Ti decreases it.

In the case of REM inclusion, it has been known that due to the acceleration of arc stability, the arc length is extended and the size of molten droplet increases, and consequently molten pool is disturbed resulting in the easy generation of blow holes. On the other hand, according to the welding made by using other types of steel, it has been reported that Zr is effective to reduce the generation of blow holes. The above might contradict with previous statement. Thus it is presumable that the study in this field is insufficient.

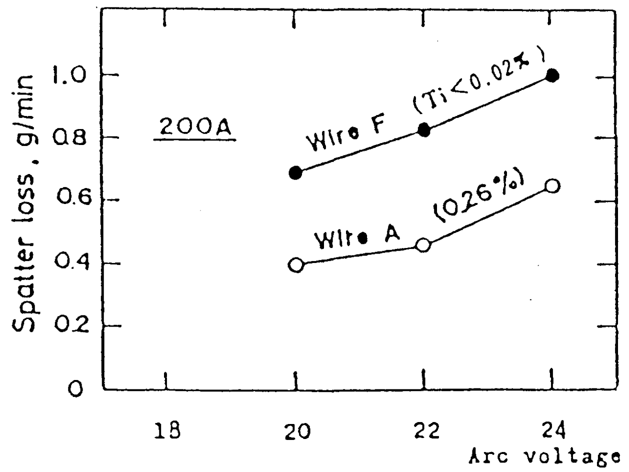

Fig. 3 Effect of Ti contained in wire on spatter loss[8]

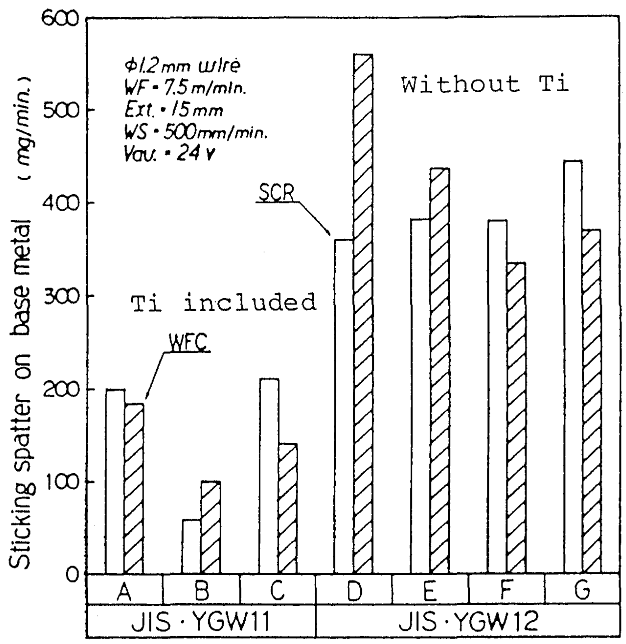

Fig. 4 Effect of Ti in wire on spatter sticked on base metal[9]
WFC : waveform controled
SCR : thyristor type

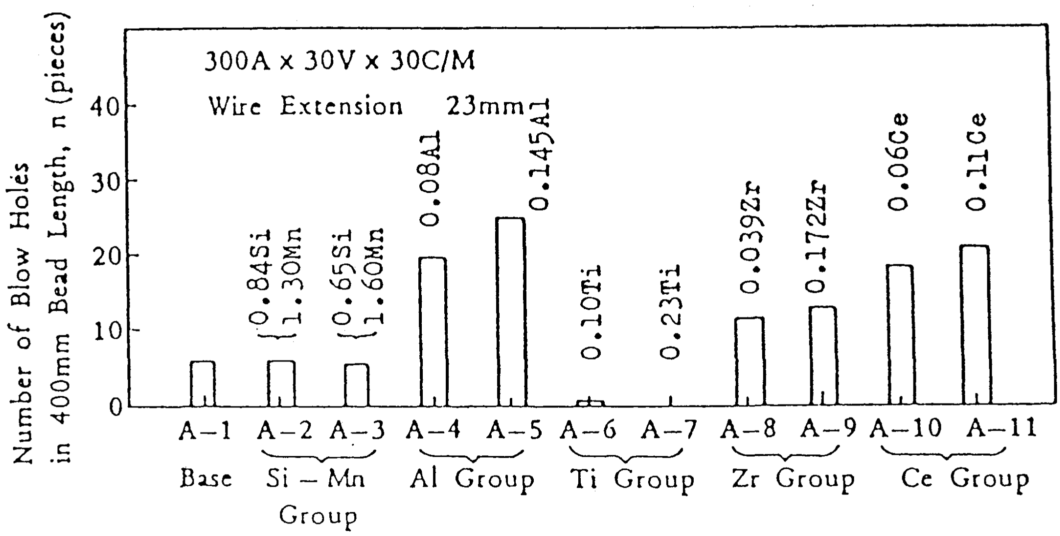

Fig. 5 Effect of blow-hole generation in weld metal of first layer in V-groove CO_2 arc welding.[10]

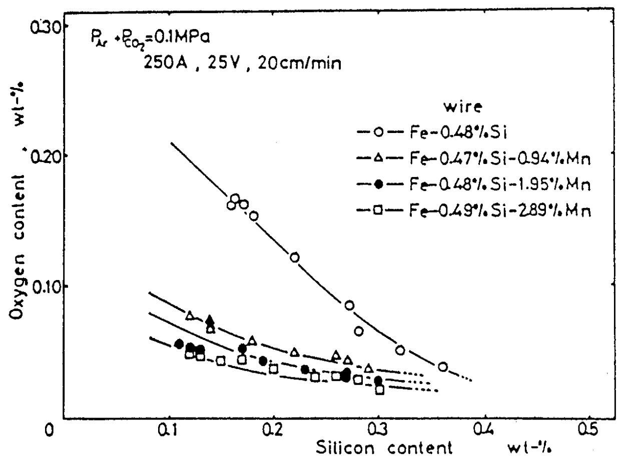

Fig. 6 Effect of Mn addition on Si deoxidation[12)]

In recent years, the generation blow holes in the MAG welding process for the welding of galvanized steel sheet comes into problem. To solve such problems, the research and development activities of weld wire are made extensively. In practice, metal flux wire generates less slag and ease to eliminate Zn vapor. In addition, the above is provided with the stabilized shortcircuiting and the stirring of molten pool which makes effective the floating of gaseous Zn, is excited under convenient condition. It is reported that the increase of C, Ti, P is effective for the suppression of blow hole[11)].

A-5) Amount of Oxygen contained in weld metal

In the MAG welding made under the ambient atmosphere of Ar + CO_2 mixing gas, the influence of deoxidizing element on the oxygen content in weld metal has fundamentally studied[12)].

In this experiment, pure iron plates were used. Then Si and Mn minor elements were added to the wire. The experiment results are shown in **Fig. 6**. Referring to **Fig. 6**, the deoxidation effect obtained by the mixed addition of Si-Mn is remarkably observed.

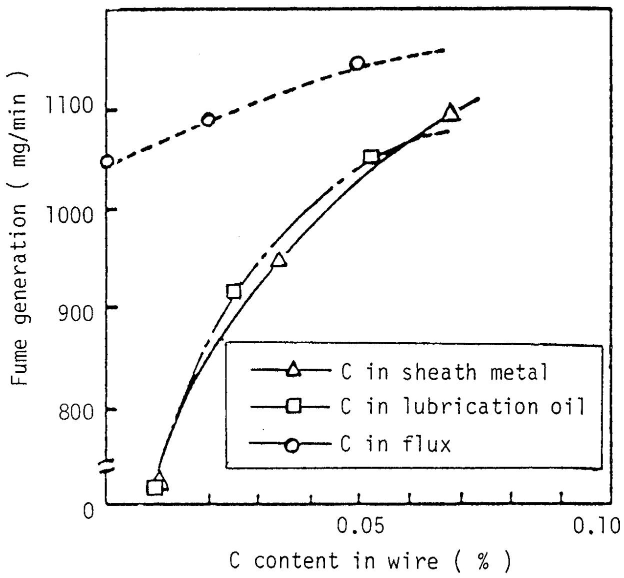

Fig. 8 Effect of C in wire on fume generation[14)]
(Wire : 1.6 mm ϕ, 300 A)

A-6) Generation of Fume[13,14)]

The results of the experiment on the effect of wire composition on the generation of fume in the solid wire CO_2 welding are shown in **Fig. 7**. Furthermore, similar experiment results by using the flux cored wire (used in the CO_2 ambient atmosphere) are shown in **Fig. 8**.

Referring to these figures, it is apparent that the decrease of C and S, as well as the increase of Mn, Si and Al minor elements in the solid wire can contribute to reduce the generation of fume. In particular, when the flux cored wire is used, the decrease of C can effetively reduce the generation of fume.

(B) Effect of minor elements in Base metal

In line-pipe steels, the addition of REM and Ca minor elements is widely used. Practically, the addition of these minor elements effects considerably upon the arc phenomenon.

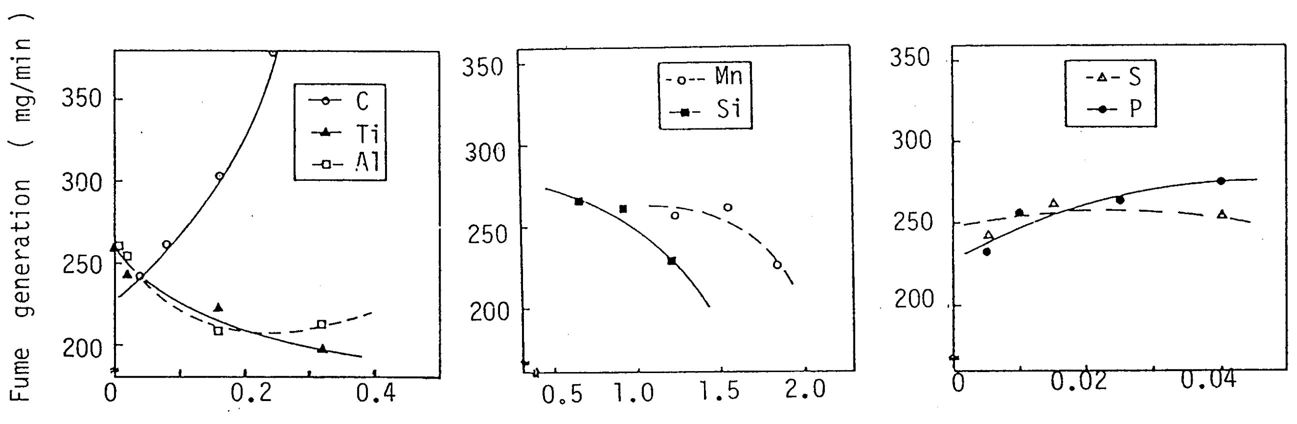

Fig. 7 Effect of minor element in wire on fume generation [13)] (1.2 mm ϕ, 150 A, 21 V)

The experimental results on the effect of the addition of 0.012–0.061% REM to steel materials in CO_2 weiding phenomenon are studied[15]. The wire contains 0.1%C–0.51%Si–1.15%Mn. Whenever the amount of REM has exceeded more than 0.02%, the arc length increases and the size of molten droplet increases proportionally, resulting in the loss of regularity in the shortcircuiting transfer. As a result, the smoothness of beads is lost.

The welding condition using REM addition steel have been studied in detail. The relationship between applied arc voltage, number of shortcircuiting occurrence and the amount of spatter has been reported. (Refer to Fig.9)

(C) Effect of Shielding gas

The kinds of shield gases used for the GMA welding is sophisticated, and practically most of them have been classified into the XII-590-74.

In the MIG welding within the range of 200 ~ 300A, for the stabilization of arc, very small amount of oxygen is sufficient preferably 0.5% O_2 or 1.0% CO_2, which is shown experimentally using 9% Ni-steel[16].

It is also reported that the Ar-He-CO_2 gas is effective for the improvement of molten droplet transfer when the electric current is very high. The relationship between the molten droplet transfer mode and the mixing rate is illustrated[17]. (Refer to **Fig. 10**)

Furthermore, the molten droplet transfer mode in the case of double gas shielded torch, as well as spatter amount, and generation tendency of porosity is now being studied in relationship with the electric current, voltage and wire feeding condition[18].

(II) TIG (GTA) Welding

In the study of the influence of minor elements on the TIG welding phenomena the effect of surface active elements, represented by S and Ce, on weld penetration, is picked up most frequently. However, firm and decisive factors are not found in the stabilization of penetration up to now.

This study theme was taken up as the subject of international cooperative study as one of VAMAS Project, in which Japan has been participated to the project, and thus, the fundamental studies are now continued.

As one of practically applicable studies, adequate welding condition is investigated, in which the relationship between the welding speed, welding electric current and penetration is examined in detail by using steel plates in which SUS304 stainless steel's S-contents were varied within the range of 0.002 ~ 0.062%[19].

For the tungsten electrode which is used in the TIG welding, fundamental and vigorous R & D study was conducted, and thus, integrated report has been submitted[20]. Actually a new type tungsten electrode in which 2% of La_2O_3, Y_2O_2 and CeO_2 is contained singularly or compositly with appropriate mixing ratio has been developed. It has been proved that the electrode is superior especially to the durability. The motivation of this study is due to the facts that conventionally used ThO_2-tungsten is not always provided with sufficient durability, and moreover, the Th is a radio-active element. In addition, in order to cope with the introduction of industrial welding robots and automatic welding machines, tungsten electrodes which ensure immediate and good performance of arc start. For the newly developed electrode in Japan, a study group has been established in the JWS, in which the excellent property of such electrodes has been recognized[21].

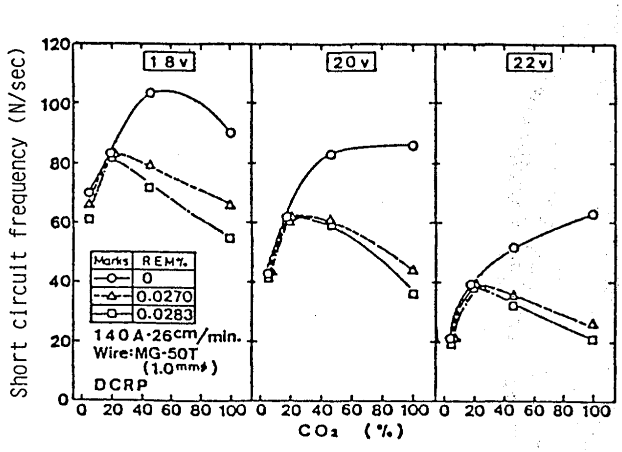

Fig. 9 Effect of CO_2 content in shield gas on short circuit frequency with REM wires[15]

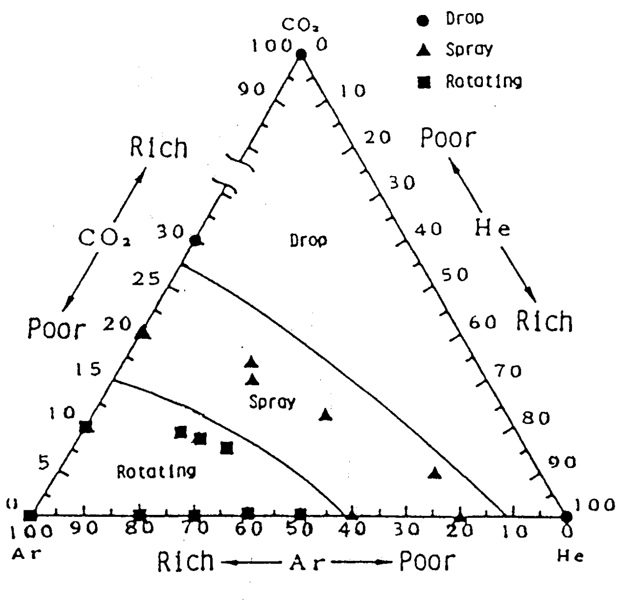

Fig. 10 Effect of Ar, He and CO_2 mixture ratio on metal transfer[17]
(500 A, 38-40 V, 30 cm/min, ex25mm)

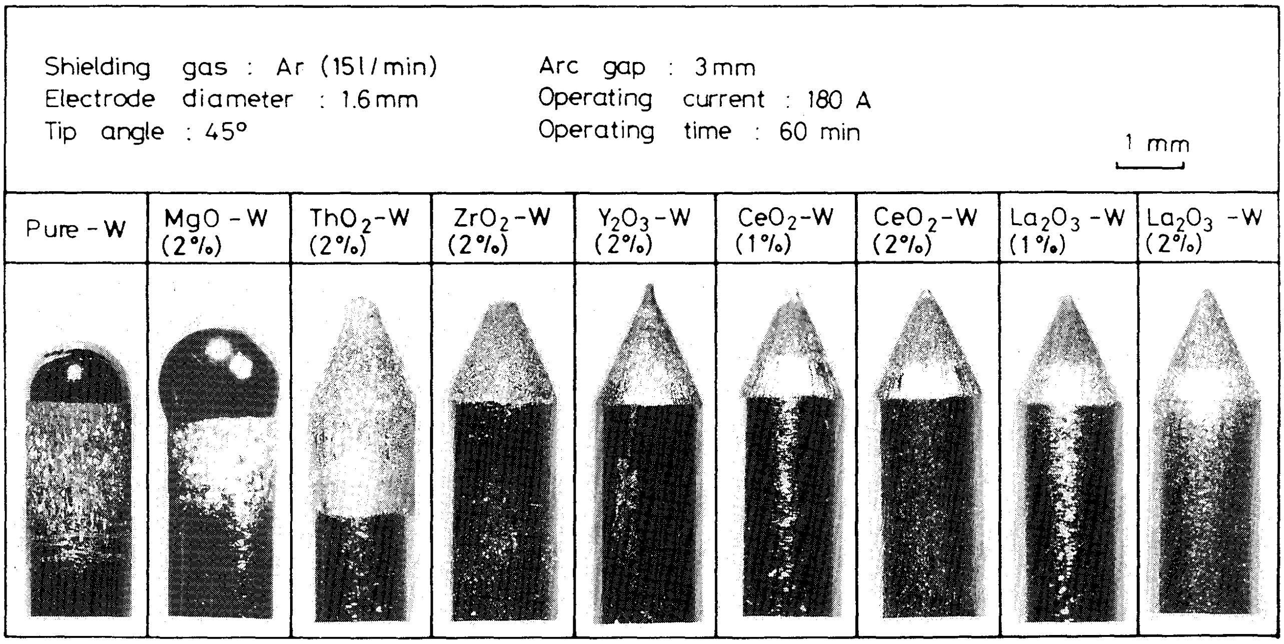

Fig. 11 Change in shape of electrode tip due to heavy loading[16)]

The shield gases used in the TIG welding are mainly represented by Ar and He. Moreover, partially, Ne may be used.

The mixing ratio of He-Ar mixture is now fumdamentally being studied about the influence on the heat transport efficiency to the base metal[22)].

In the TIG welding of the active metals represented by Ti and Zr, the purity of shield gas and its effects are now being studied[23,24)]. In both cases, the following fundamental studies on how far the influence extends when minor amount of oxygen partial pressure and nitrogen partial pressure were applied to metallurgical and mechanical properties of weld metals, are made.

Furthermore, the study of TIG welding at high-pressure has been made incessantly since early times. This welding conducted at elevated pressure is related with the welding made underwater. The pressure to be applied is ranging from the atmospheric pressure to practically 50 atm. Electrode consumption rate and the arc phenomenon are being studied in the He shielding[25)]. Under the high-pressure, arc is not always stabilized due to strong thermal pinch. Therefore, it is recommended to utilize any arc stabilizer or like for the matter, which involves many problems to be solved.

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