Development of Gas-shielded Arc Processes in Automatic Welding*

Masao USHIO

Professor Emeritus, Osaka University, yamadaoka, Suita, Osaka 567, Japan

President, College of Industrial Technology, nishi-koya , Amagasaki, hyogo661-0047, Japan
E-mail: ushio@cit.sangitan.ac.jp

***Portevin Lecture on the occasion of 62nd IIW Annual Assembly, Singapore 2009**

Abstract

Recent development of arc welding processes is described particularly focused on automatic GMA and GTA welding. The reliability of weld quality and productivity has been remarkably improved by introduction of automatic control of welding phenomena. Those progresses have been fundamentally pushed forward with developments of digital control of welding power source and the allied technologies including welding consumables and shielding gases. The state-of-the-art of these process-systematization and corresponding advances of constituent technologies is mentioned, and the role and future direction of our welding technology are discussed.

1. INTRODUCTION

It is needless to say that welding is the most essential technology for manufacturing all of metal structures. In particular the arc welding has been the most widely used one in various welding processes. It is because that arc process costs very low despite of its great convenience for use and has a extremely wide applicability.

In consequences, the arc process has remarkably progressed in past 30 years through the intense requirement of technological innovation aiming "increase in productivity", "stabilization of weld quality" and "labor saving". Recently those aims are collected and summarized comprehensively to the function of advanced automatic welding.

Of course, it is not always possible to set up a pertinently functionalized automatic welding system, because that the details of requested function are dispersified depending upon used materials, shape and size, welding process applied, heat treatment before and after the welding and so on. However, the increase in productivity and the stabilization of weld quality are fundamentally common demand of all technological development and it would be linked to advanced automatic welding.

In this paper, recent progresses of gas–shielded arc welding, in particular, those of GMA and GTA processes and their trends of technological development in Japanese manufacturing sites are described and discussed about the strategy of direction of these developments.

2. DEMAND FOR AUTOMATIC WELDING

Since 1990, the Japan Welding Society has investigated every four years the current situation of arc welding process technologies, particularly automatization technologies and their future trends, for the welding sectors of a variety of manufacturing companies. The statistical data obtained from the investigation results have been published in the Commission XII of the IIW. In the earlier investigation, it was made clear that strong demand for the welding technologies in all industrial fields of manufacturing included the following,

- Higher welding speeds for cost savings,
- Easier welding processes and robotization to overcome lack of skilled welders and welding operators, and
- Solution to the welding of low weldability materials such as composite materials and new performance materials.

The top two items of demand are the same as those clarified in the current investigation on automatization welding technologies.

In the investigation results obtained in 2007 (Figure 1), clearly the purposes of automatization and robotization highlight these two items of demand at high ratios [1]. In addition, automatization and robotization are beginning to be taken as the key technologies to secure improved productivity and consistent quality as well as the measures to meet such narrow purposes as labor savings and unmanned work. That is, automatization and robotization are the basic purposes and aims for the current welding technologies.

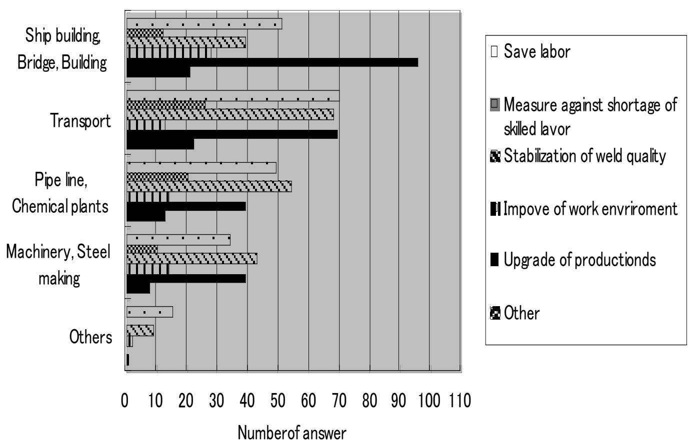


Fig.1 Purposes of automaticzation, robotization.

By the way, what technical constituents are needed for configuring such a welding system that provides improved productivity and highly consistent weld quality? Such technical constituents are shown schematically in Figure 2.

It goes without saying that the arc phenomena in arc welding is a governing factor for developing high efficiency, high deposition, and for promoting the accuracy of welding performance control. Figure 3 shows characteristic time of variety of arc phenomena, comparing with output characteristic time of wire feeding [2].

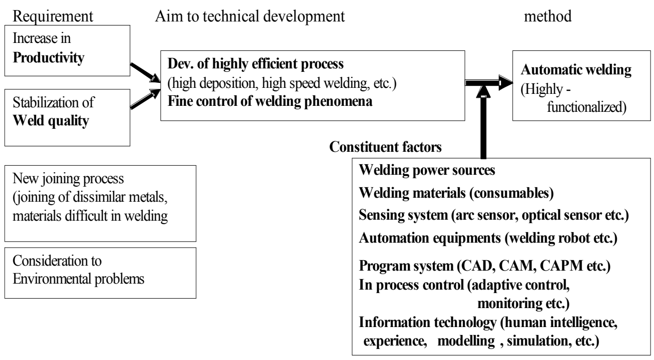


Fig.2 Recent requirements for welding production technology and its integration to automatization

present pulsed MAG/MIG welding power source, was developed 1980. This type of pulsed power source was marketed as the world first transistor-controlled welding power source. However, three years later, in 1983, inverter-controlled welding power sources were put into full-scale production.

Since then, the advancement in welding power sources has highly functional high-performance welding power sources combined with microcomputer control was developed in 1990. In the end of 20th century, adoption of digital control for welding power sources began in full swing with a background of the advancement in digital control technologies, and most of the control circuits were changed from analog control to digital one, and recently speed up of the output control by using high speed control devices has actively been promoted.

All the requirement for welding power sources for controlling the welding arc phenomenon fall into the advances in high speed response, precision stability, and wide range of applicability. The approximate range of operational frequency that takes place in each phenomenon or the characteristic time for each phenomenon is shown in Figure 3, which varies very widely from 1 sec. to 10 μsec.

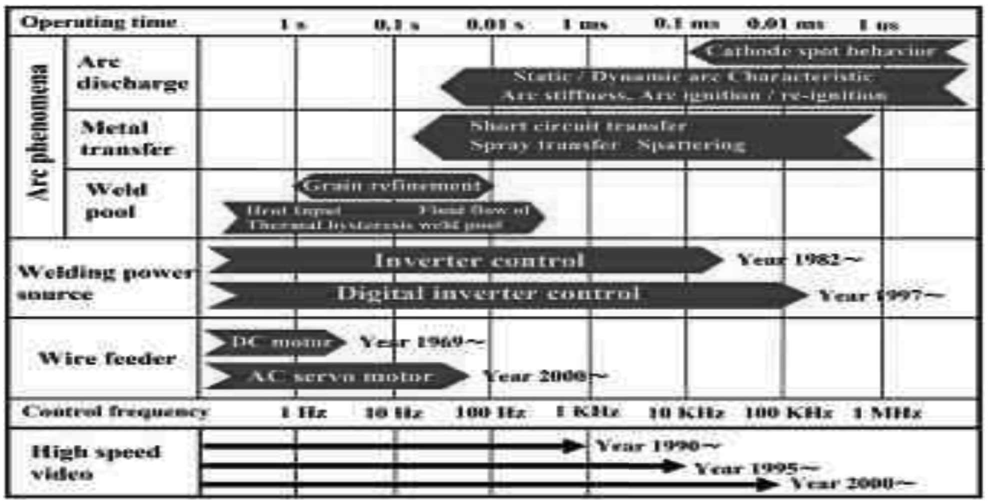


Fig.3 Relationship between arc phenomena and output control of welding equipment.

3. DEVELOPMENT OF WELDING POWER SOURCES

The trends in the development in the main control technologies for arc welding power sources in recent years can be summarized as shown in Figure 4[3]. Thyristor-controlled power source became commercially available in 1969, which provided synergic control, thereby enabling the welding sequence control and the improved operational performance. The pulsed power source equipped with the synergic pulse processor, which was the prototype of the

In the figure, the controllable frequency ranges for welding power sources and wire feeders are also shown for comparison. From both data, it is obvious that the improvement in the response of power sources enables to expand the range of phenomena that a power source can control directly.

As is well known, the arc of GMA welding is applied between welding wire and mother metal. The wire metal is formed into molten metal droplets at the electrode part of wire end mainly by arc heat, and transferred periodically to

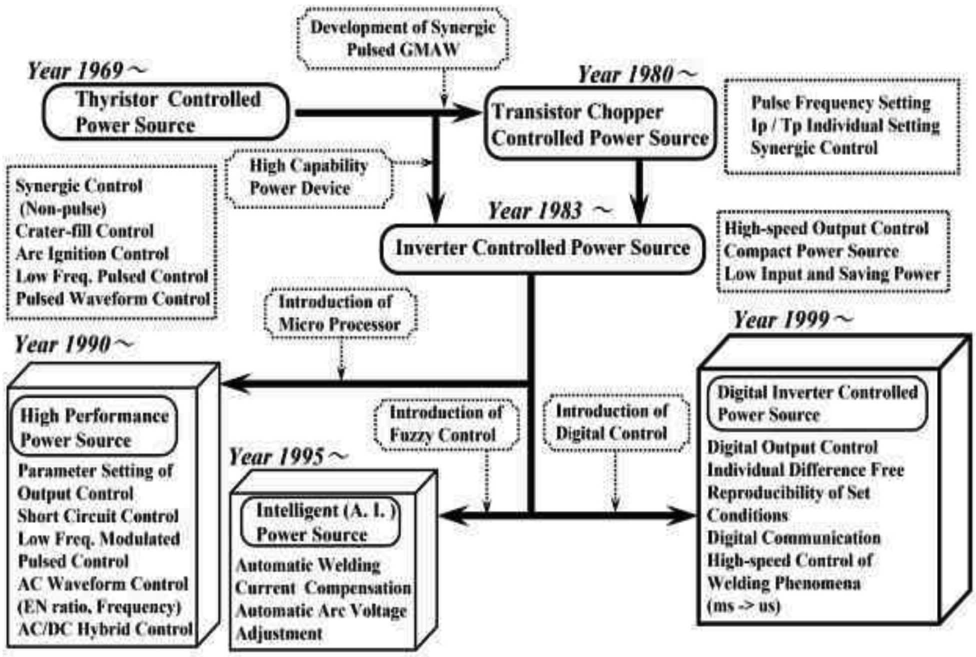


Fig.4 Trends in developments of main control technology for arc welding power source.

molten pool on the mother metal. Namely, the arc length and the arc spot position change intermittently. This means the GMA is not a substantially stable heat source in time and space. And therefore, it could be mentioned that the regularity of metal transfer phenomenon give the serious influence on the productivity and the quality of weld.

The aim of the development of welding power source has been concentrated to regularize metal transfer phenomenon and to increase metal deposition rate and penetration depth, by the control of current and its waveform, so far.

With thyristor-controlled power sources, the welding workability has a close relationship with the configuration of hardware. Especially it had significantly been affected by the characteristics of the DC reactor. Digital-controlled power source has been developed to replace the DC reactor with electronic reactor , in which CPU creates precisely controlled effects, that is to say, the control circuit creates an appropriate effective inductance (di/dt), equivalent in response to a load fluctuation in the short-circuit duration and the arc duration so that an instantaneous currents changes gradually. Furthermore, in order to control the arc current and voltage directly without conventional output control by the above-mentioned reactor, a high-speed controlling of output waveforms has created by means of digital computation with the CPU.

The most burdensome problem in workability of GMA welding is the occurrence of spattering. The several kinds of mechanism of spattering has been made clear [andou], however, the one associated with restart of arc just after the break of short-circuiting is most serious. Since the spattering phenomena is very fast and complicated, the understanding has not been enough so as to suppress the spattering entirely only by the control of current waveform. Recently a digital-control technology of wire feed rate has been developed and applied simultaneously with the fine digital-control of current cooperatively, and thereby the generation of spatter in CO_2 arc welding with medium current could be suppressed completely. One of these processes is called as CBT (Controlled Bridge Transfer) and is shown in Figure 5[4].

As stated above, the digital-control of power source attached with digital-controlled wire feeder, has a very high potential for highly precise control of GMA welding phenomena. It might be create the new high-quality welding process in which the arc is extremely stable like GTA without missing the important characteristics such as the high deposition and high efficiency. However, in order to realize it, it is necessary to improve upon the software so as to optimize immediately the combination of output variables such as current, voltage, wire feed speed and so on. Namely, the phenomena occurred in arc and molten pool region should be understood fully and related with control variables of digital-controlled power source.

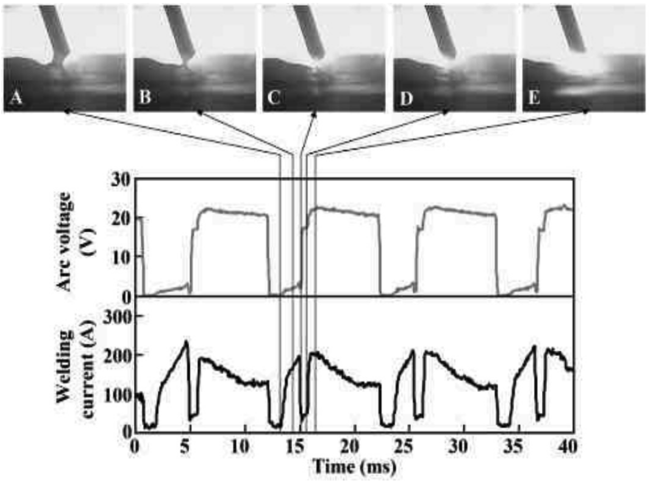


Fig.5 Metal transfer and related current and voltage waveforms by CBT. process

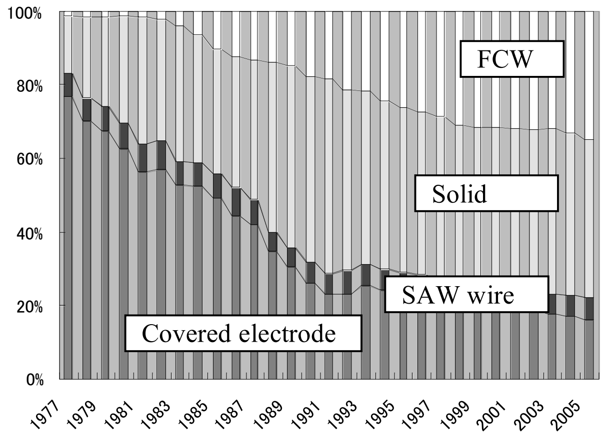


Fig.6 Change in annual production of various types of welding consumables in Japan.

4. DEVELOPMENT OF WELDING CONSUMABLES

Figure 6 shows the trend in the annual production of various types of welding consumables in Japan in recent years [5]. The sum of solid wire and flux cored wire (FCW) reaches 80 % of total amount of each year production. From the standpoint of improving the stability of weld quality and of upgrading fabrication efficiency, high performance of welding consumables including shielding gases are desirable as well as that of welding power source. In the case of solid wire, chemical composition of bulk metal of wire and properties of cu-coating layer are the main factors available to improve its performance, on the other hand, FCW has many factors to adjust such as compositions of contained flux and metal powder, their amount, shape and size of sheath metal and so on. These two types of welding wire could not always have the same target of development, however, a variety of consumables with high performance has been developed. Here those consumables with high performance related to high productivity and stabilization of weld quality are introduced and discussed, mainly in the heavy industry [6].

In the shipbuilding and bridge construction industries, metal type FCWs for the fillet welding of primer-coated steel plates and slag type FCWs for all position welding have been used persistently. Recently corresponding to the increase in thickness of structural members of the bridges, a new FCW has developed, which generates a large amount of slag with high viscosity, thereby providing a single-run fillet weld with a large leg length of up to around 10 mm, as shown in Figure 7. This type of large-leg FCW has also been put into practice for weather proof steel in addition to 490 N/mm^2- and 590 N/mm^2-class high strength steels. In block-to-block joining and robotic welding for hull construction in shipbuilding, welding consumables with excellent weldability in all position welding are intensely demanded. Figure 8 shows an excellent performance on large gap joints in vertical-up welding with high current. This FCW produces a high-viscosity molten metal and slag of high melting point so as to increase the self-supporting force of molten metal.

These slag type of FCW above mentioned, however, have inferior hot crack resistance and thus tend to generate solidification cracks in the root pass in one-sided butt welding and in the filling passes in narrow grooves, this is why such specific welding requires using low welding currents. To overcome this problem, new flux type FCW has developed and played a high performance for root pass welding now.

In the steel structure building industry, 540 N/mm^2-class solid wires (YGW18 per JIS) have been used persistently, which ensure the required weld quality even in large heat input welding with high interpass temperatures. As shown in Figure 9, the weld metal of this type of wire has superior mechanical properties even in large heat input with high interpass temperatures in comparison with a conventional wire (YGW 11 per JIS). On the other hand, this wire (YGW 18) contains large amount of alloying elements to obtain high-strength and high-toughness weld metals and thus generates much slag. This slag-rich nature degrades the performance of the wire in continuous welding by robot. A new low-slag YGW 18 wire is developed to to solve above problem, which is designed to have the elaborate chemical composition of metal part to reduce slag as well as securing the strength and toughness of the weld metal.

Improvement in the process efficiency has been progressed by employing multiple electrodes. In the shipbuildings industry for instance, conventional twin-tandem horizontal fillet welding by the line welders has been improved in welding speed by employing the twin-3-electrode welding process that uses the third filler wire between the two electrodes. In this advanced process, the newly developed metal-type FCW was used as the third wire connected to the

DCEN power source, and thereby the arc interferences between electrodes decreases and weld pool was stabilized much. Consequently with this process, porosity can be prevented and excellent bead can be obtained at a high speed of 2 m/min which is far faster than the upper limit of 1.5 m/min with the former process.

As shown in preceding chapter, pulsed GMA welding power sources have been used extensively to reduce spattering, in automatic welding of car industries. In this trend, the non-Cu-coated solid wire has been developed. This wire features special surface treatment instead of Cu-coating to provide stable and smooth wire feedability and electric contact at the tip, and thereby realizing high welding speed, low spatter and low fumes in pulsed GMA welding.

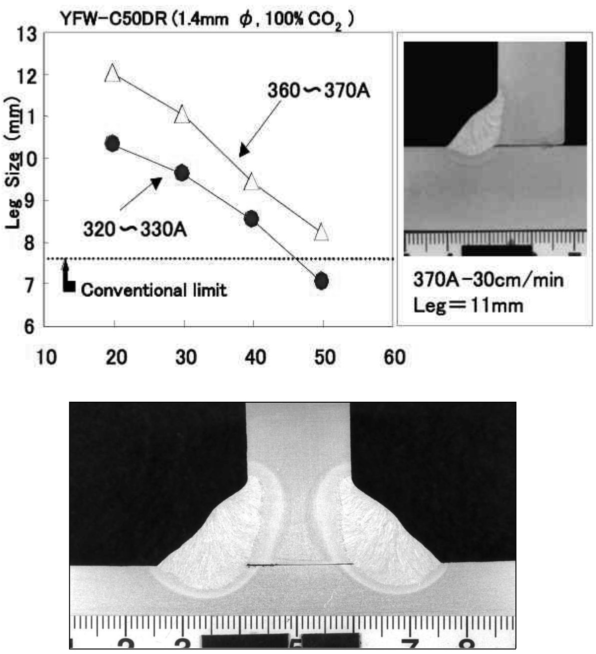
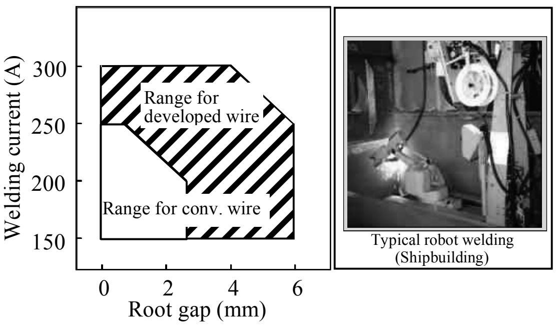
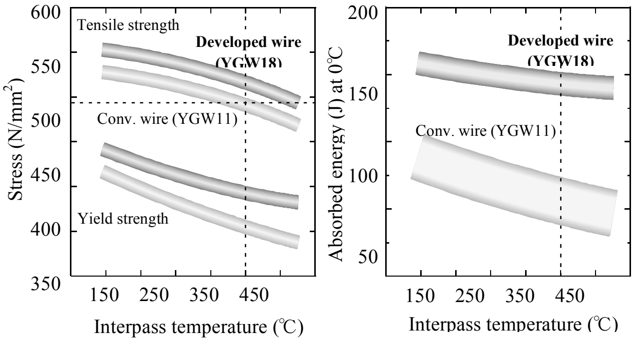


Fig.7 Performance of large-leg fillet FCW.
Lower:High-speed rotating, tandem 2-pool arc.



(Wire dia.: 1.2mmφ; Shielding gas: CO_2; Vertical-up fillet welding)

Fig. 8 Performance of FCW for vertical-up welding.



(Wire dia.: 1.4mmφ; Welding heat input: 40kJ/cm)

Fig.9 Performance of 540N/mm2 class wire (YGW18).

5. ON HIGHLY-ADVANCED CONTROL OF GMA PROCESS

The welding wire can take some different roles in GMA welding, that is, to work as a electrode of arc, to become molten metal droplets and fly to weld pool and in consequence form the deposited metal. On the other hand, when the wire is directly inserted into the pool like the filler wire of GTA welding, the wire could give a great influence on the pool shape and its temperature distribution, the volume of molten metal and the behavior of convection in the pool. It is possible to say that the wire play a very important role as a fundamental factor to control the welding process. In the former section, an example in which the wire inserted in the weld pool as the third electrode of 3-electrode welding made a contribution to reduce the arc interference between two electrodes and to stabilize the weld pool is shown.

Metal transfer in GMA welding with mixed gas shield (Ar80%+$CO_2$20%) changes its mode from the short-circuit transfer to the globular transfer and further to the spray transfer (projected, streaming and rotating transfer), as increasing the current. The threshold values of the mode changes and the regularity of metal transfer phenomenon have wide varieties depending on the materials properties of the wire, the composition of shielding gas, the stability of welding current and so on. As mentioned above the energy (heat) and its space- and time-distributions inputted into the weld were also influenced by the metal transfer phenomena seriously.

Recently some analyses of the complicated metal transfer phenomena by computer simulation have been made and the results have shown the very interesting aspects though it is only the limited case. The computer simulation could not give satisfactory result yet; this hopeful approach should be used much more for many complicated welding phenomena [7].

6. RECENT DEVELOPMENT OF SHIELDING GASES

A shielding gas affects mainly the molten metal transfer and in turn largely affects the welding phenomenon and quality in GMA weld. The reason for this can easily be understood in consideration of that the metal transfer strongly relates to the electromagnetic force and arc plasma stream induced by the current, the arc pressure, the surface tension of metal droplet and adjacent molten metal, and the gravity force. This is why various gases have been developed as the operating gases, which are detailed in the textbook. However, how the metal transfer affects the heat transfer in the weld pool and how it affects the spatter generation have not been understood sufficiently. This subject will be briefed in the following in relation to the development of a special shielding gas for GTA welding.

GTA welding is known as a considerably high quality welding process. On the other hand, it has drawbacks of shallow penetration and low welding speed. However, in the end of the last century, the active-flux-coated TIG welding process developed by the Paton Institute provided deep penetration depths of 2-3 times that with a conventional TIG welding process. This innovative process roused at a dash many researchers' interests about the mechanism of increasing penetration; as a result, they have been actively researching to develop more accomplished processes. For example, a stainless steel filler wire that contains a special flux to control the convective heat transfer in the weld pool has been developed and practiced (Figure 10 [8]).

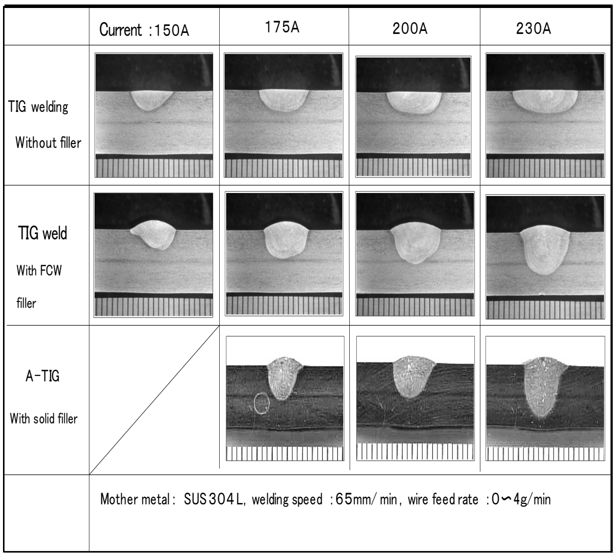


Fig.10 Penetration depth of TIG welding with FCW containing active-flux as filler wire.

Such technical developments in TIG welding that intend to improve productivity include a special coating flux that controls penetration in various shapes and a precision dual shielding torch using an oxidizing gas and an inert gas.

7. STATE-OF-THE-ART OF AUTOMATIZATION AND SYSTEMATIZATION

The target for the development of control technology has been changing with progress of automatization in welding; that is, in addition to the development of various sensors for tracking the welding line, the adaptive control of welding conditions in response to the groove shape, work shape, and welding position has become the development target. The current status of and several technical developments in the adaptive control are described here [9]. Figure 11 shows the purposes of using sensors and the number of the sensing systems used in the welding sites. In this figure, it is obvious that sensors are used mostly for groove tracing control, work piece edge sensing, and welding conditions adaptive control. Such sensors are mainly arc sensors, electrode touch sensors, and optical sensors. There are many combinations of optical sensor and CCD camera, which are expected to become popular for the future. Figures 12 and 13 show how such a sensing system senses groove shape in narrow groove welding and detects post-weld surface defects.

Many combinations of sensors and other devices mentioned above are evolving to become systematized, including the entire welding equipment and its performance control. This tendency has been clearly pointed out since more than last ten years, mainly in the shipbuilding industry, but the development is not necessarily fast.

An unattended welding system is shown, which has been operated for one year or longer in Japan. In this system, the groove shape and location are sensed just before welding with a laser sensor, and, if such variables are changed during welding, automatic welding is executed by adaptive control of welding conditions in response to the changes. Also, with this system, post-weld surface defects can be detected with the laser sensor.

When this system is used for all position welding, the welding conditions may have to be changed momentarily in response to variable positions, gaps and misalignment during welding. Figure 14 shows a schematic diagram of such parameter controls. Figure15 is showing an example of automatic welding system [10].

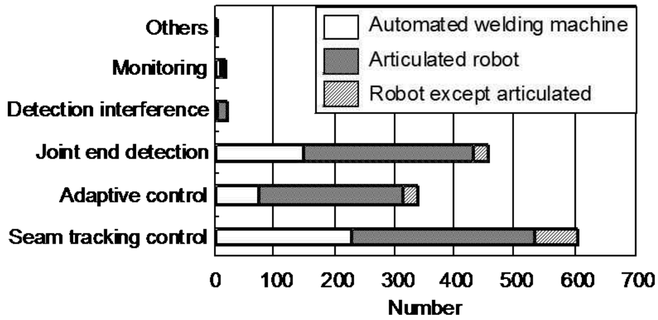


Fig.11 Purposes of using sensers.

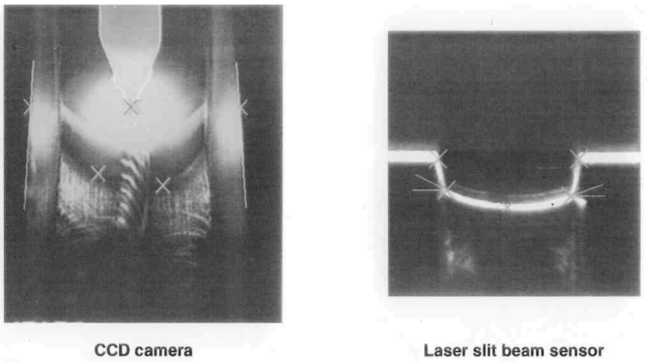


Fig.12 Example of optical sensor for measuring shape of groove.

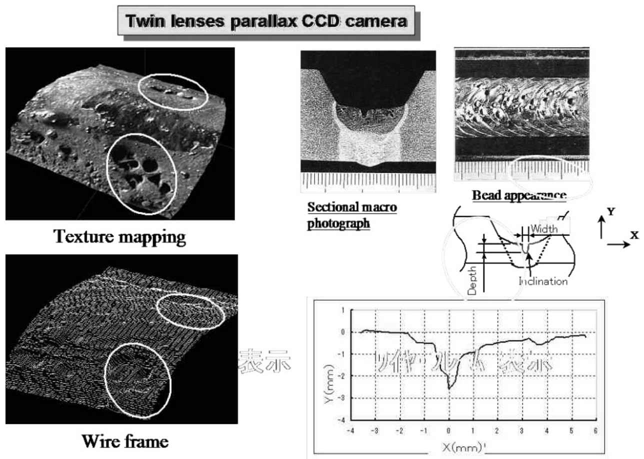


Fig.13 Defects detection by twin leaser parallax CCD camera.

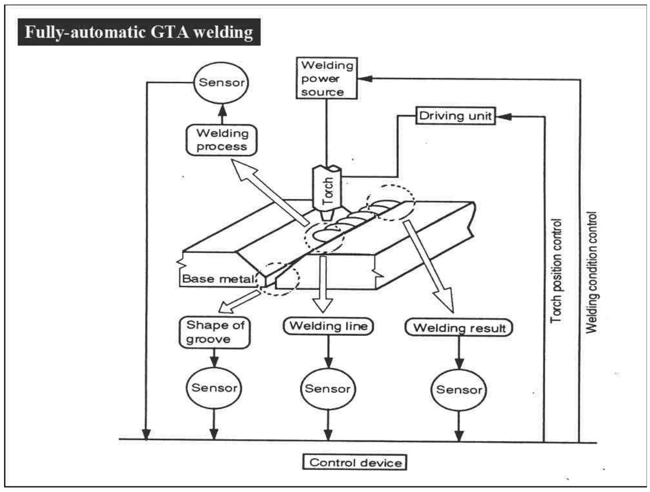


Fig.14 Concept of automatic welding.


Fig.15 An example of small automatic welding system.[11].

8. FUTURE DEVELOPMENT AND CHALLENGES FOR HIGHER PERFORMANCE -CONCLUDING REMARKES-

As mentioned at the beginning of this article, welding is the essential technology for manufacturing. And the fundamental requirements for manufacturing technology are the high efficiency in fabrication and reliability of products. In order to meet the demands the development of advanced automatic welding has been persistently pushed on.

Of recent welding production technologies, the trends in technical developments that strongly relate to automatic arc welding have been described. Technologies discussed here do not cover all the developments, and the discussions are limited, but they are all practiced in industrial applications. The directions of future technical developments have also been pointed out with several challenges.

Last but not least, it is human beings that develop and apply highly automated welding technologies with such important performance; therefore, it should be emphasized that engineers' in-depth understanding of the welding system is most important because the welding system is the most basic technology for the fabrication of structures.

REFERENCES

[1] Tech. Comm. Welding Processes (JWS); Journal of JWS, vol.77 (2008) No.2, p.9~48, (in Japanese).

[2] H.Yamamoto; J. of JWS, vol.66 (1997) No.8, p.615~629, (in Japanese).

[3] T. Mita; J. of JWS, vol.69 (2000) No.3, p.190~196, (in Japanese).

[4] T.Ueyama et.al.; Welding Technique, vol.54(2006)No.12, p.60~67, (in Japanese).

[5] Data of the Japan Welding Rod Association, (in Japanese).

[6] F.Koshiishi; J. of JWS, vol.77 (2008) No.2, p.38~43, (in Japanese).

[7] Y.Hirata et. al.; Quarterly J. of JWS, vol.22 (2004) No.2, p.224~232, (in Japanese).

[8] E.Ashida et.al., Doc. JIW XII. 2244, (2009) Feb., (in Japanese).

[9] Tech. Comm. Welding Processes (JWS); J. of JWS, vol.77 (2008) No.2, p.10~26, (in Japanese).

[10] M.Ushio et al.; Dunhuang China Welding Forum (Invited lecture), Aug., (2004).

[11] K. Kamo ; Private communication.