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Recent Activities in Research of Welding

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The body can be viewed from the next page.

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1 Introduction

Welding and joining technologies are playing important roles in all steel using industries and have been advanced responding to various changes in the social environment and market requirements.

The last ten years was a decade of violent changes for the Japanese economy and we experienced both the so-called Heisei-Izanagi boom supported by a sharp rise in land prices and the long depression caused by the collapse of the bubble economy which was swollen by the boom. This also meant a large change in the environment for the steel industry as a basic industry in Japan as well as for the welding technology as a processing technology for steel. At this time, it may be necessary to review this period of violent changes and to think of the direction to which our studies on welding should be advanced from here looking toward the 21st century. In this paper, we summarize the last ten years' major progress in the studies of the welding technologies in Kawasaki Steel.

2 Research Activities in Welding Technology

2.1 Welding Materials

The shipping trends of welding materials for Japan[1)] are shown in **Fig. 1**. The total shipping quantity dropped to less than 300 000 t/y in 1987 during that period's depression due to the appreciated yen and it recorded about 420 000 t/y in 1991 by being supported by the Heisei-boom. However, the steel industry then turned around and reduced production after the collapse of the bubble. Although the total shipped quantity has been maintained at about 350 000 t/y since 1995, severer conditions are forecast for the future. If we analyze the trends for each kind of welding materials, it can be seen that solid wires (GMAW) rapidly formed a large market

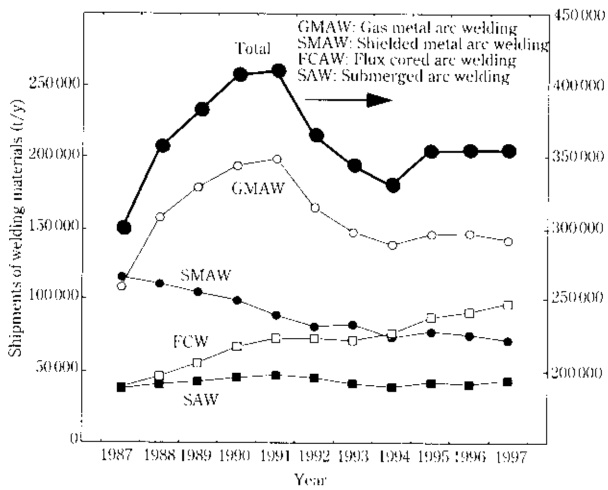

Fig. 1 Shipping trends of welding materials in Japan, including export

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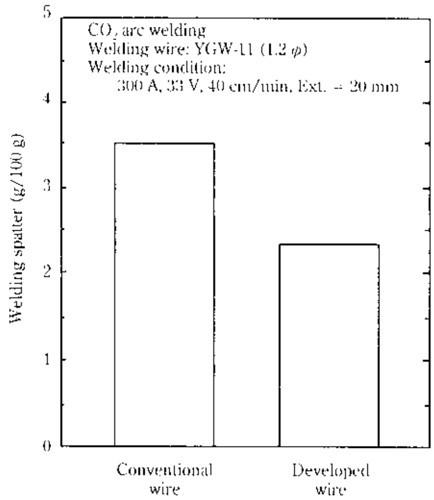

Fig. 2 Comparison in the amount of the welding spatter in CO_2 arc welding between the conventional and newly developed wires

in the first half of these ten years. In the background of this rapid change, it can be pointed out that gas metal arc welding using solid wires was the most suitable welding method for automation and robotization for the purpose of labor saving and de-skilling. On the other hand, shipments of covered arc welding rods (SMAW) constantly decreased and that of flux cored wires (FCW) remarkably increased instead and is expected to continue this trend. The shipped quantity of submerged arc welding wires and flux (SAW) is the least and has kept nearly constant in these 15 years.

Under such circumstances, we positively engaged in R&D for welding materials with "high efficiency and high quality" as the keywords in order to meet the social requirements.

If a large amount of welding spatter is generated in the automation and robotization of gas metal arc welding, gas shielding is impeded by the spatters stuck onto the gas shielding nozzle and the quality of welding is impaired. In order to cope with such inconvenience in adopting automation, we energetically carried out development for reducing spattering. In order to reduce spattering in CO_2 arc welding, suppressing the increased voltage gradient due to contraction of the arc is an important point in development. Accordingly, we found out that by adding chemical elements with low ionization energy to wires, the increase of the voltage gradient due to thermal ionization of CO_2 can be mitigated and the localized concentration of the arc can be also reduced. Based on this idea, we have developed the new solid wire for CO_2 arc welding (KC-50-DH) which have successfully reduced spattering in welding. A comparison of the quantity of spattering in CO_2 arc welding between conventional and the newly developed wire is shown in **Fig. 2**.

Responding to the need to reduce spattering for a further improvement of quality also in MAG welding, we developed low spatter wire (KM-50S) for pulse MAG welding. Reduction of spattering was achieved by adjusting the droplet viscosity resulting in stable detaching of droplets from wires when applying pulses.

In the case of developing flux cored wires (FCW), stable feedability of wires becomes an important point as in the case of solid wires. Therefore, we positively made studies on the surface characteristics of wires as well as on the lubrication and developed FCW which have both excellent welding workability and superior feedability. Attaching importance to the environmental problems in welding in recent years, further low fume FCW are in the process of developing. Furthermore, with respect to FCW for primer coated steel plates which are widely used in shipbuilding and bridge construction, we developed the new FCW for this specific use (FG-50P). In order to suppress the generation of pits and wormholes due to the formation of primer gas and zinc gas caused by the heat of welding, the wires of this type are designed not to allow any bubbles to remain in the weld metal by adjusting the solid/liquid ratio at the solidification of welding slag. Many high-rise buildings were built during these 10 years, especially in the second half of the 1980's and in the first half of the 1990's. This trend made it necessary to enhance the efficiency of fabricating various structural members, such as box columns and weld-built H shaped steel with heavy plates. For the purpose of meeting such requirements, we actively developed a submerged arc welding (SAW) procedure for deep penetration with high heat input as well as a kind of iron powder added bonded flux. Through X-ray fluoroscopic direct observation of the behavior of the molten pool in high heat input SAW, it was made clear that in order to achieve deep penetration, it is important to limit the volume of molten metal flowing in just below the arc of the leading electrode by reducing welding current of the trailing electrode. On the basis of this knowledge, two-electrode SAW method[2] was established for the welding of corner joints of 60 mm thick box columns. Furthermore, the above-mentioned one-pass welding for 60 mm thick plates was made possible even with a low output power source up to 2 000 A by adopting 5.1 mm diameter thin wires for the leading electrode because of deep penetration due to high current density.[3] In addition to the above, we developed a three-electrode one-pass SAW method for 80 mm thick heavy plates by optimizing various factors such as groove configuration and distance between electrodes. An example of cross-sectional macrostructure of the weld obtained by this method is shown in **Photo 1**.[4]

2.2 Welding Technologies for Steel Sheet

Since the latter half of the 1980's, surface coating of thin steel sheets for automobile use rapidly became common for the protection of car bodies from corrosion and

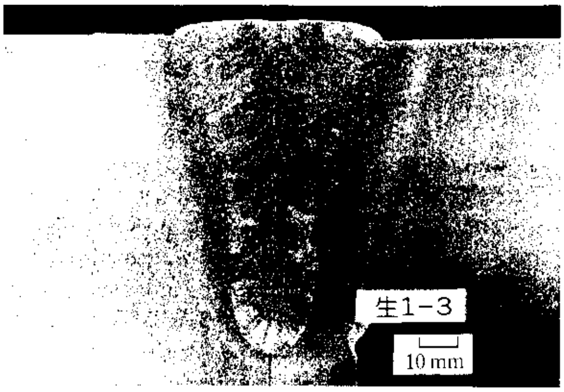

Photo 1 Cross sectional macrostructure of the 3-electrodes, 1 pass submerged arc welding for heavy section plate of 80 mm in thickness

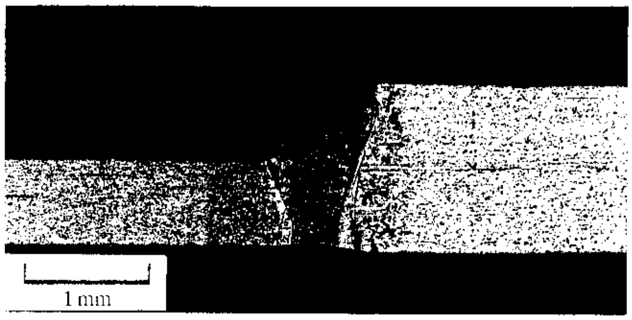

Photo 2 Example of the laser welded joint of the sheets of different thickness, i.e., 0.7 and 1.4 mm in thickness, welding condition; 4.6 kW, 4 m/min

problems related to weldability of coated steel sheets have arisen accordingly.

If zinc coated steel sheets are lapped and arc welded, zinc in the clearance between the lapped sheets is vaporized by the heat of welding and blows out in the weld metal, thus forming blowholes by being trapped in solidifying weld metal. In order to prevent this phenomenon, it is necessary to suppress the generation of zinc gas. Therefore, we developed a method to prevent vaporization of zinc by applying FeP_2 beforehand over the sheets in the vicinity of the weld portion in the clearance of the lapping sheets so that the FeP_2 reacts with Zn due to the welding heat.[5]

Furthermore, if zinc coated steel sheets are resistance spot welded consecutively for many times, zinc on the sheet surface diffuses into the welding electrode and forms a hard brittle Cu-Zn alloy layer, and thus the electrode is heavily worn. The welding current density is also lowered resulting in weld nuggets not being formed. We tackled this problem from the raw material side and analyzed the above mentioned electrode wear phenomenon[6] and clarified the relationship between the configuration of the electrode face and nugget formability.[7] Through such efforts, we developed galvannealed zinc coated steel sheet which has a superior weldability for the continuous spot welding because of its characteristic of forming a stable tip on the electrode face.[8]

For the purpose of reducing the weight of car bodies or of using proper materials at the proper places, car manufacturers have developed and practically applied the tailored blanking process, some sheets with different functions and thicknesses were jointed together in one sheet by laser welding, etc. before blanking. Parallel with this development, we studied on laser welding procedures for steel sheets of different strengths, thicknesses, etc. and the press formability of the laser welded joints of these sheets.[9,10] An example of a laser welded joint of different thick steels is shown in **Photo 2**.

2.3 Welding Technologies for Thick Plate and Steel Pipe

In the field of welding for thick plate, this ten year span was also a decade of returning to heavy, thick, long and large structures as represented by superhigh-rise buildings, long large bridges, etc. For the application of super high heat input SAW and electro-slag welding to extremely thick steel plates, we energetically studied the improvement of mechanical characteristics of weld metals and the heat affected zone.[11-13] Furthermore, the needs for further high tensile strength and high alloys for the purpose of excellent corrosion resistance were materialized. We advanced our studies on the production of API X80 and X100 grade steel UOE pipes and duplex stainless steel UOE pipes by means of SAW as well as the application of HT980 steel to penstocks for pump-up power stations. For welding of HT980 steel, our studies focussed on developing welding methods and welding materials which do not generate hydrogen cracking even at low preheating temperature while maintaining high strength and sufficient toughness of the weld metal. Even for shielded metal arc welding which contains the large amount of diffusible hydrogen and has a high cold cracking susceptibility, we solved the above mentioned difficult problems by optimizing the carbon and carbon equivalent contents of weld metals. Thus, low preheating temperature of 75°C have achieved for preventing the cold cracking in HT980 steel.[14]

A remarkable factor in the field of thick plate welding is that the beam power of CO_2 laser welding machines was dramatically increased in the period from the 1980's to the 1990's and 45 kW class welding machines which are fully applicable also to thick plates have been made commercially available. Aiming at the application of welded joints by high power laser beam to various structures, we carried-out basic studies on the metallurgical performance of laser weld metals including cooling characteristics, chemical composition, microstructures and toughness.[15,16]

3 Closing Remarks

Major studies on welding in these ten years made by Kawasaki Steel were reviewed in this paper. As mentioned in the beginning, progress in welding technologies is always closely related to the social environment and market requirements and the welding technologies were the keys which determined the commercialization of steel materials. We believe that this trend will not change in the next century as well and welding and joining technologies covering a wider area will become important in order to deal with new materials which are expected to be more diversified and improved.

References

1) The Japan Welding Rods Association, Statistics committee: "Shipping Amount of Welding Materials in 1997", June, (1998)
2) S. Sakaguchi, T. Yamaguchi, and Y. Nakao: "Behavior of Molten Metal and Optimum Welding Conditions of High Heat Input Submerged Arc Welding with Flux Containing Iron Powder", *Quarterly J. of the Jpn. Welding Soc.*, **13** (1995)3, 384
3) S. Sakaguchi, N. Hayakawa, and K. Yasuda: "High Efficient Submerged Arc Welding with Finer Diameter Electrode for Corner Joint of Box Shaped Columns", Preprints of the National Meeting of the Jpn. Welding Soc., **63**(1998), 172
4) N. Hayakawa, S. Sakaguchi, K. Yasuda, and Y. Kataoka: "Influence of Welding Conditions on Penetration Depth in Tree-Wire Submerged Arc Welding for Thick Steel Plates", Preprints of the National Meeting of the Jpn. Welding Soc., **57**(1995), 118
5) K. Yasuda, S. Nakano, T. Yamaguchi, T. Komatsu, and T. Nakajima: "Avoidance of Blowhole in Arc Welding of Galvanized Steel Sheets", The 5th Int. Symp. of the Jpn. Welding Soc., (1990), 5JWS-IV-36, 785–790
6) R. Ikeda, K. Yasuda, T. Yamaguchi, and C. Shiga: "Resistance Spot Welding of Galvannealed Steel Sheets (Report 2)", Preprints of the National Meeting of the Jpn. Welding Soc., 47(1990), 154
7) R. Ikeda, K. Yasuda, T. Yamaguchi, and C. Shiga: "Resistance Spot Welding of Galvannealed Steel Sheets (Report 1)", Preprints of the national meeting of the Jpn. Welding Soc., **47**(1990), 152
8) C. Kato, K. Yasuda, M. Masuda, A. Yasuda, and N. Morito: "Effect of B Addition into Ultra-low Carbon Steel Substrate on Spot Weldability of Galvannealed Steel Sheet", *CAMP-ISIJ*, **5**(1992)2, 665
9) Y. Kitakani, K. Ohi, K. Yasuda, and Y. Nakao: "Effect of Weld Bead Properities on Formability of Laser Welded Steel Sheets", Preprints of the National Meeting of the Jpn. Welding Soc., **55**(1994), 42
10) Y. Kitani, K. Yasuda, and Y. Kataoka: "Formability of Laser Welded Joints with Filler Wire", Preprints of the National Meeting of the Jpn. Welding Soc., **57**(1995), 456
11) N. Hayakawa, S. Sakaguchi, K. Yasuda, and Y. Nakao: "Effects of Cooling Rate and Chemical Compositions on Toughness of High Heat Input, One Pass Submerged Arc Weld Metal", Preprints of the National Meeting of the Jpn. Welding Soc., **61**(1997), 194
12) N.Hayakawa, S. Sakaguchi, K. Yasuda, and Y. Kataoka: "Parameters Controlling Toughness of Weld Metal Made by Three-Electrode, One Pass Submerged Arc Welding for Heavy Section Box Columns", Int. Inst. of Welding, Doc. No. IX-1839-96 (1996)
13) M. Nishimori, T. Hayashi, F. Kawabata, and K. Amano: "Intragranular Microstructure Control of Very Large Heat-Input Welding Heat Affected Zone", *CAMP-ISIJ*, **10**(1997)3, 592
14) R. Ikeda, K. Ohi, K. Yasuda, and Y. Nakano: "Weld Joint Design for HT980 Steel with Low Cold Cracking Susceptibility for Penstock Use", Symp. of Welded Structure '97, the Jpn. Welding Soc., (1997), 29
15) K. Yasuda, Y. Kitani, and T. Misawa: "Metallurgical Characteristics of CO_2 Laser Weld Metal for Heavy Steel Plates", Document of the 29th High Energy Beam Proc. Committee of the Jpn. Welding Soc., HEB-307-98 (1998)
16) T. Misawa, S. Takasa, Y. Nakano, and K. Yasuda: "Ductile-Brittle Transition Evaluation of Laser Welded Steel Metal", *Tetsu-to-Hagané*, **82**(1996)8, 707