DEVELOPMENT OF HYPER INTERFACIAL BONDING TECHNIQUE FOR ULTRA-FINE GRAINED STEELS

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ABSTRACT

This paper describes the concept and the characteristics of *hyper interfacial bonding* developed as a new concept joining process for UFG (ultra-fine grained) steel. Hyper interfacial bonding process is characterized by instantaneous surface melting bonding which involves a series of steps, namely, surface heating by high frequency induction, the rapid removing of heating coil and joining by pressing specimens. UFG steels used in this study have the average grain size of 1.25 μ m. The surface of specimen can be rapidly heated up and melted within 0.2s. Temperature gradient near heated surface is relatively steep, and peak temperature drastically fell down to about 1100K at the depth of 2~3mm away from the heated surface of specimen. Bainite is observed near bond interface, and also M-A (martensite-austenite) islands are observed in HAZ. Grain size increases with increasing heating power, however, the grain size in bonded zone can be restrained under 11 μ m. Hardened zone is limited to near bond interface, and the maximum hardness is Hv350~Hv390.

KEYWORDS

Hyper interfacial bonding, UFG(ultra-fine grained) steel, microstructure, grain growth, instantaneous heating

1. Introduction

Recently, UFG(ultra-fine grained) steel whose chemical composition is almost similar to mild steel has been developed. In general, UFG steels have superior properties, for example, high strength, high toughness, good workability and good weldability. Besides, UFG steels are favorable to recycling because of manufactured by limiting alloying elements. At present, SUF steel (steel with surface-layer of ultra fine grain microstructures) is used as the important parts of large-sized ship and LPG carriers due to its good crack arrestability[1,2]. Hence, UFG steel is expected to being used for welding structure of earthquake-proof building and sea plant in the future. On the other hand, from a practical viewpoint, welding and joining technique for UFG steel is indispensable for being used as a structure material. The weldability of UFG steel for conventional arc welding and laser welding is excellent, because it has simple chemical composition and contains low alloying element. However, in HAZ or weldment, material properties fall down less than base metal due to the grain growth by weld heat input. Hence, the new bonding technique which does not harm to the properties of the HAZ and the weldment is requested. This paper is intended that the development of *hyper interfacial bonding* technique as the most efficient bonding technique to UFG steels.

2. Material and experimental procedure

Chemical composition of the UFG steel used in this study is given in Table 1. UFG steel as-received has the average grain size of about 1.25 μm and the tensile strength of 1120 MPa. Microstructure of the UFG steel is shown in Fig.1. The dimensions of specimens is 5×5×30 mm. After etched in 2% nital, the microstructure was examined by optical and SEM microscopies. In order to measure the grain size of prior austenite, sample was etched in picric acid hyper saturated solution. Grain size was evaluated by linear intercept method. Vickers hardness in joint was measured at the load of 0.49N.

3. The concept of *hyper interfacial bonding*

The bonding equipment and the vacuum chamber developed are illustrated in Fig.2. The *Hyper interfacial*

Table 1 Chemical composition of UFG (ultra-fine grained) steel.

C	Si	Mn	P	S	Nb	Ti	Al	N	Fe
0.15	0.20	2.30	0.01	0.0001	0.03	0.09	0.025	0.029	Bal.

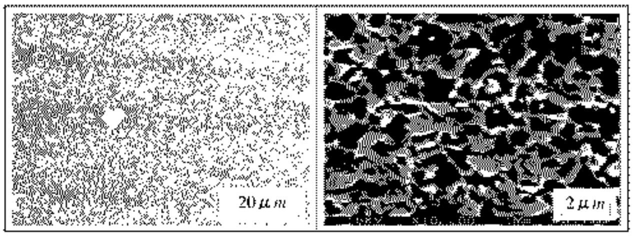


Fig.1 Micrographs of UFG steel examined.

bonding system is consisted of the high frequency power source of 1 MHz and 70 kW, an oil pressure system and a vacuum chamber including heating coil. The *hyper interfacial bonding* process is characterized by the instantaneous surface melting bonding. Each procedure in this bonding process can be explained as follows.

(1) adjust the gap between heating coil and specimen

(2) heat only the surface of specimen in a moment

(3) have heating coil moved back rapidly.

(4) complete bonding by pushing down on fixing jig worked by oil pressure system

In particular, all procedures were completed within about a half second, and also specimen could be heated up and melted rapidly within 0.2 second. These procedures are illustrated schematically in Fig.3. The higher heating power and heating time, the better heating rate is. The temperature gradient near heated surface was relatively steep, and peak temperature has drastically fallen down at 2~3 mm away from the heated surface.

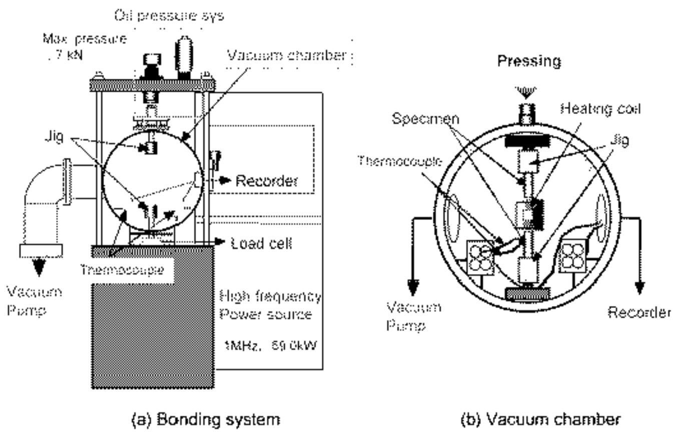


Fig.2 Schematic of hyper interfacial bonding system.

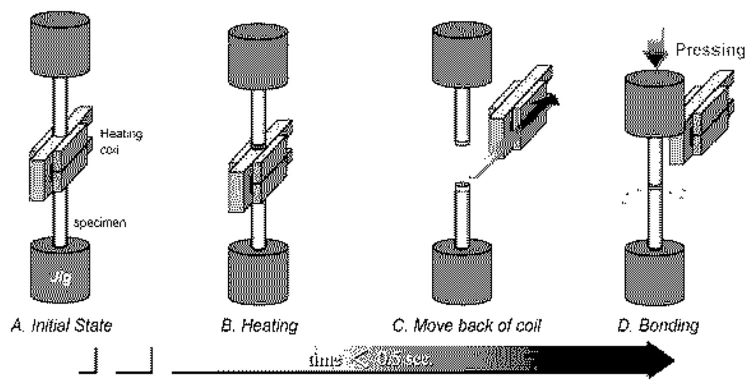


Fig.3 Schematic illustration of the procedure of hyper interfacial bonding.

4. Heating profile by *hyper interfacial bonding* system

Fixed heating time to 0.17s, the relation between distance from the heated surface and the peak temperature with heating power is shown in Fig.4. It is found that specimens are intensively heated in the region near 1mm away from the heated surface. In this region, temperature decreases slightly with decreasing heating power, and heating profiles are maintained steeply. Though heating power increased, the width of HAZ is hardly changed. Hence, it is needed to carry out the bonding at the condition of high heating power as possible.

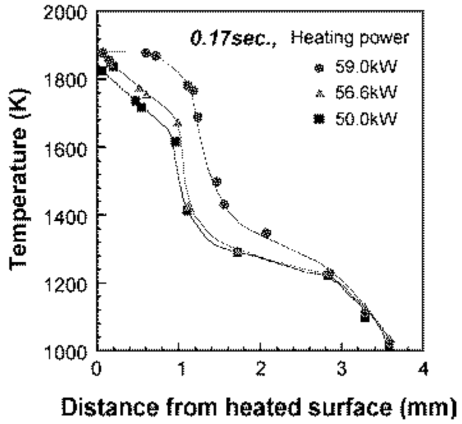


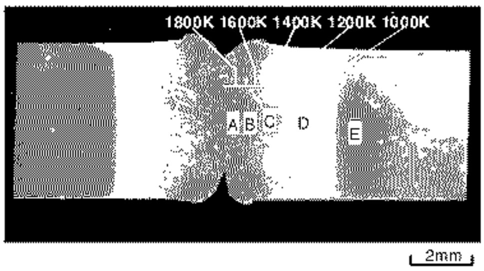
Fig.4 Temperature distribution of the specimen heated by hyper interfacial bonding system.

5. Microstructural analysis of joint

5.1 Microstructure in bonded layer

Fig.5 shows the microstructure of the joint bonded at 59kW for 0.20s applying the upset of 0.15mm. The width of HAZ from bond interface is approximately 3.5mm. From the bond interface, it appears that fusion zone, coarse grained zone, fine grained zone and base metal in order. Bainite and grain boundary ferrite including widmannstatten ferrite side plate precipitated from the prior austenite grain boundary are observed in near bond interface. Ferrite and pearlite appear at 2.5mm away from bond interface. Fig.6 shows the SEM microstructure of the joint bonded at 59kW for 0.20s applying the upset of 0.15mm.White intragranular M-A constituents are observed at 1.5mm away from bond interface, and those are observed at ferrite grain boundary at 2.2mm away from bond interface[3]. Namely, M-A constituent is changed from the intragranular to the intergranular with going away from bond interface. Fine white cementites are observed at ferritic grain boundary as well as M-A constituents at 2.8mm away from bond interface.

-Heating power : 59.0kW
-Heating time : 0.20s
-Bonding atmosphere : 1.33×10^{-3}Pa
-Bonding pressure : 2.0kN
-Gap : 0.5mm
-Upset depth : 0.15mm



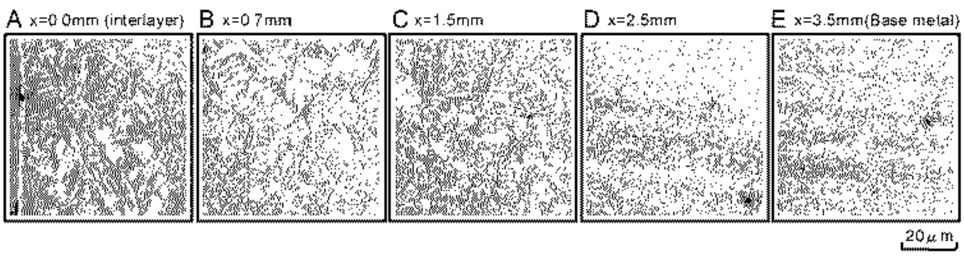


Fig.5 Optical micrographs of the joint bonded by hyper interfacial bonding.

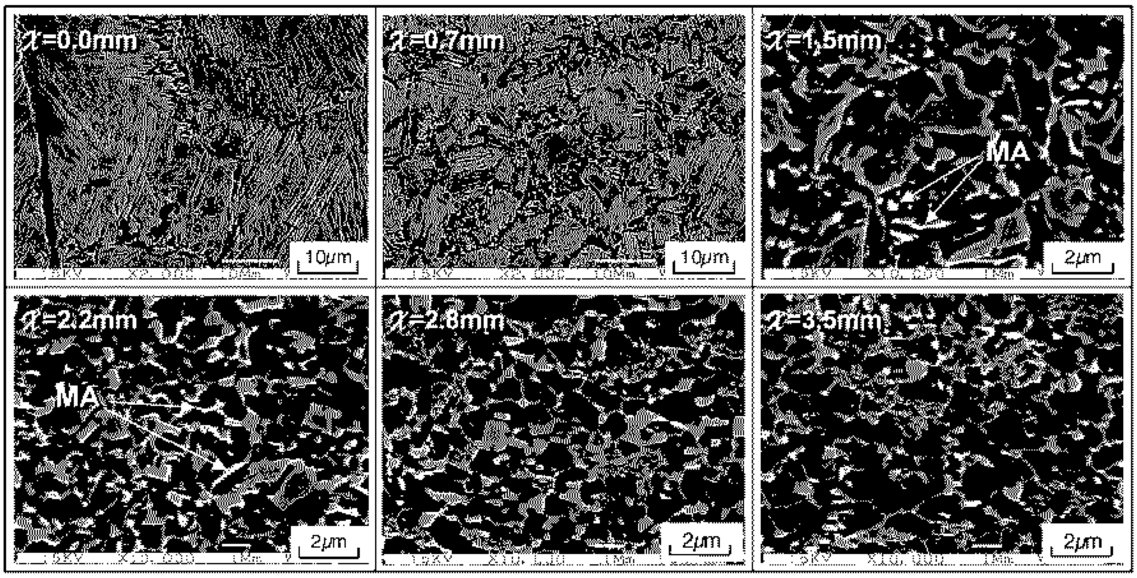


Fig.6 SEM micrographs of the joint bonded by hyper interfacial bonding.

5.2 Hardness and Grain size

Fig.7 shows the hardness distribution of the joint bonded at 59kW for 0.20s compared with the hardness distribution by other fusion welding processes. There is softening zone in the low temperature region of HAZ in TIG weldment, however hardness came down hardly in hyper interfacial bonding because of the appearance of M-A. The hardness and the width of the HAZ of the hyper interfacial bonded joint are similar to those of CO_2 laser welded joint. Fig.8 shows the grain size distribution compared with other welding processes. The width of the HAZ of EB welded joint was the narrowest. And, the maximum grain size of hyper interfacial bonded joint was retrained under 11 μm. Though the width of the HAZ of hyper interfacial bonding is wider than that of electron beam welding, prior austenite grain size of hyper interfacial bonded joint is smaller than that of EBW.

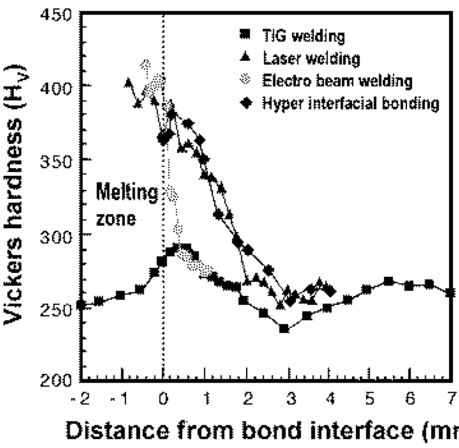


Fig.7 Hardness distribution compared with other processes

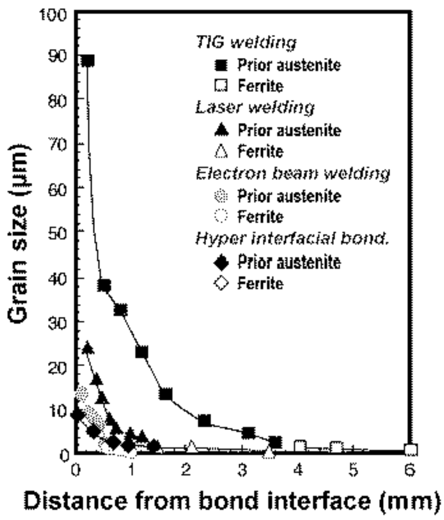


Fig.8 Change of grain size during the bonding process respectively.

6. The superiority of *hyper interfacial bonding* on UFG steel

The superiority of *hyper interfacial bonding* on UFG steel was evaluated from the microstrucural viewpoint. The microstructural characteristics of fusion welded joint and hyper interfacial bonded joint are shown in Table 2. Microstructure near bond intrface was ferrite+bainite in TIG welding, bainite in laser beam welding, martensite+bainite in EBW and bainite in *hyper interfacial bonding*. The width of HAZ was the narrowest in

EBW. From these results, it seems that the heating and cooling speed is the fastest among other welding processes. The maximum harness of the joint corresponded with their microstructures. EB welded joint was hardened most, and the TIG welded joint was scarecely hardened. Also the softening zone of HAZ existed in TIG welding. The maximum grain size of hyper intrfacial bonded joint was approximately two-thirds of EBW, and approximately a half of LBW. This result means that the grain growth of hyper interfacial bonded joint is restrained most compared with other fusion welding processes.

From these results, it is suggested that the *hyper interfacial bonding* developed in this study is an advanced bonding technique. And, the hyper interfacial bonding, applied to UFG steel, is able to restrain the grain growth of joint sufficiently and restrict the heat effect on base metal.

Table 2 Microstructure, grain size and hardness compared with other welding processes.

	TIG welding	LBW	EBW	Hyper Interfacial boding
Microstructure (near fusion line)	Ferrite-Bainite	Bainite	Martensite-Bainite	Bainite
HAZ width (upper Ac_3)	3.6mm	1.3mm	0.5mm	1.4mm
Max. Hardness	Hv307	Hv385	Hv413	Hv380
Hardening Zone	1.8mm	2.0mm	0.8mm	2.6mm
Softening Zone	2.0mm	Not formed	Not formed	Not formed
Max. Grain size	89.8 μm	25.3 μm	15.0 μm	10.1 μm

4.Conclusions

In the present report, *hyper interfacial bonding technique* was newly developed and applied to bonding of UFG steel. The conclusions are summarized as follows;

(1) Heated temperature near bond interface increased with increasing heating power and heating time.

(2) Bainite and grain boundary ferrite were observed near bond interface. M-A constituents, produced in HAZ, were changed from the intragranular to the intergranular with going away from bond interface.

(3) The hardness and the width of HAZ in hyper interfacial bonded joint were similar to those of CO_2 laser welded joint.

(4) Grain size increased with increasing heating power and heating time, however, grain size in bonded zone could be depressed under 11 μm in hyper interfacial bonded joint.

References

[1] Tadashi Ishikawa, Yukito Hagiwara, Hiroshi Yoshikawa, Yuuji Nomiyama and Hidesato Mabuchi : *Journal of the Japan Welding Society*, 15-1(1997), 148-154(in Japanese)

[2] Tadashi Ishikawa, Takehiro Inoue : *CAM-ISIJ* vol.10(1997), 587(in Japanese)

[3] Tadayuki Otani, Susumo Tsukamoto, Goro Arakane and Akio Ohmori : *Proc. Of the 7th Int. Simp.,JWS*, 773-779.