Newly-Developed Diffusion Bonding System for Steel Construction Material

by

Hisao Iida / Manager, Construction Technology Dept., Tokyo Office

Yasuto Fukuda / Senior Research Engineer, Tube and Steel products Research Dept., Corporate Research and Development Lab.

Synopsis

A high-speed diffusion bonding system for joining H-section steel piles on-site using amorphous metals has been developed. The characteristics of the newly-developed on-site diffusion bonding process are as follows.

(1) Joining time is quite short.

(2) The joint has microstructural continuity while the arc welding provides a micro structural change in the heat affected zone and the solidified weld metal, resulting in less deterioration of joint properties.

(3) The joint has less reinforcement, a smooth surface and is free of projections.

(4) The diffusion bonding operation is automatically controlled and the operator of this system does not require any special skills or welding techniques. Both the mechanical and welding properties of the joint are satisfactory. All of these facts are evidence that this method of joining H piles could be used for general applications.

1. Introduction

Brazing has sometimes been avoided in spite of its various advantages because it is not very reliable in terms of the mechanical characteristics and corrosion resistance of brazed joints. For example, with the Ni-B brazing powder which is often used for brazing of heat resistant alloys, there are metallurgical problems such as residues of intermetallic compounds like Ni_3B and Ni_3P in the weldment, and defects caused by oxide on the surface of the brazing powder or by flux which has not been sublimed when it is used in the form of paste[1),2)].

However, the use of amorphous filler metals in joining operations can improve normal brazing technology. A liquid film temporarily forms at the bonding interlayer during bonding and solidifies isothermally during the interdiffusion of elements to depress the melting point of the filler metal.

Consequently, excellent joint quality can be expected without any fusion welding defects.

A newly-developed, high-speed diffusion bonding system using amorphous metals has been applied for joining small and medium diameter tubulars and pipes, as well as steel bars for concrete reinforcement [3),4)]. In this paper, this bonding system for steel H piles using amorphous metals will be discussed.

2. Principle of New Diffusion Bonding System

One of the basic principles for successful diffusion bonding is placing clean metal surfaces in close contact in order to enable the interatomic forces to work. However, this is often difficult to achieve because of micro-roughness and the thin oxide film on the bonding surfaces, as shown in **Fig. 1**. Therefore, new bonding techniques having liquid and solid-state low melting phases (eutectics) were investigated.

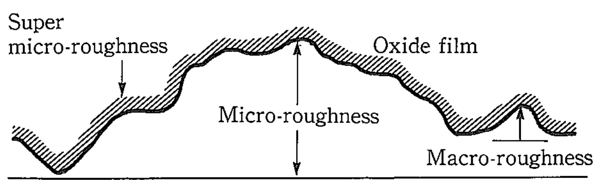


Fig. 1 Schematic illustration of metal surface for joining

A kind of liquid phase diffusion bonding process using amorphous filler metals which are eutectic compositions formed by transition elements such as nickel, iron etc., and metalloids, such as silicon and boron, is shown in **Fig. 2** in comparison with the conventional brazing process. At the bonding temperature, the interlayer initially melts, filling the gaps between the mating surfaces with a thin liquid layer.

While the parts are held at the bonding temperature, rapid diffusion of alloys such as boron occurs between the interlayer and the base metal. This change of composition at the interface region causes the joint to isothermally solidify. This analysis of isothermal solidification using a hypothetical binary phase relationship implies that it should be possible to solidify any interlayer composition without formation of deleterious second phases [5]. After isothermal solidification occurs, the joint microstructure generally resembles that of the base metal, resulting in excellent bonding properties[6].

3. Investigation of Diffusion Bonding System for Steel H Piles

A newly-developed, high-speed diffusion bonding system using amorphous metals has been applied for joining small and medium diameter tubes and pipes, moreover, steel bars for concrete reinforcement [3),4)]. Therefore, this bonding system for steel H piles using amorphous metals is investigated.

3.1 Experimental Procedure

3.1.1 Material Used

Steel H piles used had a size of 300×300×10×15 mm of SHK400 specified at JIS A 5526. The chemical compositions of and mechanical properties of steel H piles are shown in **Table 1.**

The thickness of the amorphous insert metal is about 25μm, and the melting point of the insert metal is 1 040°C. The chemical compositions of insert metal used is shown in **Table 2.**

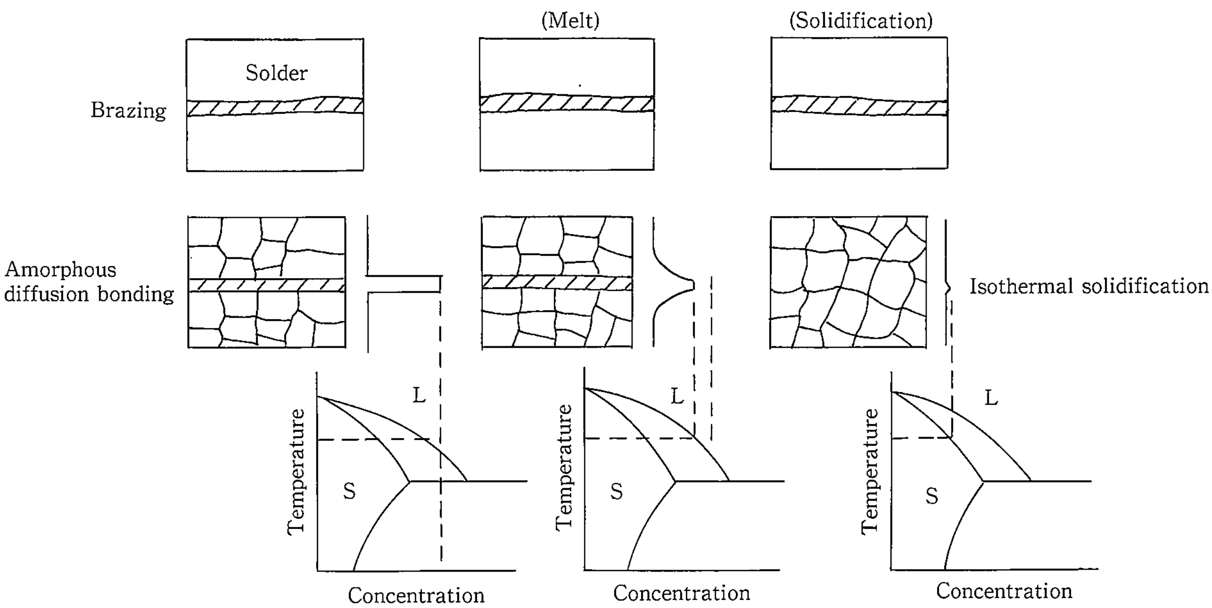


Fig. 2 Isothermal solidification by diffusion of boron

Table 1 Chemical composition and mechanical properties of steel H piles (mass %)

C	Si	Mn	P	S	YS (N/mm²)	TS (N/mm²)	El (%)
0.14	0.21	0.62	0.027	0.016	277	476	22.2

Table 2 Chemical composition of insert metal used (mass %)

Ni	Cr	Si	C	B	Solidus	Liquidus
bal.	5.3	7.3	0.08	1.4	950°C	1 040°C

3.1.2 Diffusion Bonding Equipment

Figure 3 shows the experimental welding head, and a schematic illustration of the bonding apparatus is shown in **Fig. 4.**

The upset force as well as the temperature is recorded during the bonding operation. And steel H piles are shielded by nitrogen or argon gas during the joint operation. The capacity of high frequency power source is 100kW-14kHz. The diffusion bonding operation is automatically controlled.

3.1.3 Evaluation Method

The target heating temperature was settled at 1 250°C on the basis of previous studies [3),4)]. Effects of upset distance and gap between piles on joint properties such as tensile and bending properties by small specimens were investigated. The upset distance was changed by changing upset force, and the gap was made by machined-specimen as shown in **Fig. 5.**

The fracture behaviour of bonding joint was investigated by full-scale tension and compression tests using a test rig with maximum capacity of 2 000tons.

3.2 Experimental Results and Discussions

3.2.1 Effect of Upset Distance and Gap on Joint Properties

Testing conditions are shown in **Table 3.** The gap (g) is 1 and 3mm, and the upset distance is 1, 3 and 5mm. The results of tensile and bending tests are shown in **Table 4.**

All specimens satisfied the specified tensile strength. But some specimens were observed which

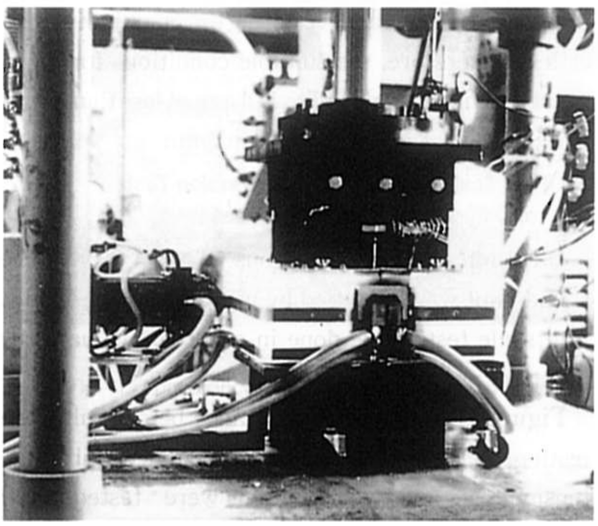


Fig. 3 Welding head of diffusion bonding system

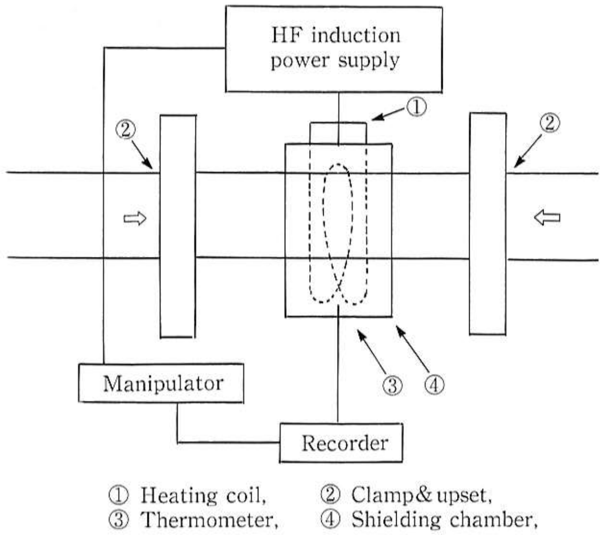


Fig. 4 Schematic illustration of bonding apparatus

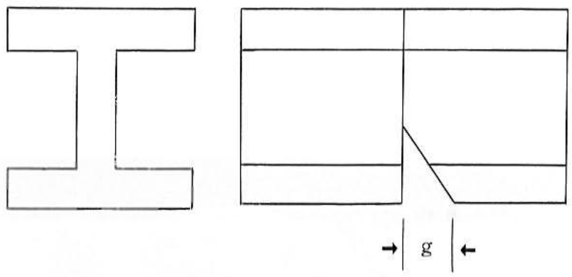


Fig. 5 Definition of gap (g)

Table 3 Testing conditions

	Gap (mm)	Upset distance (mm)
A	0	1
B	0	3
C	0	5
D	1	3
E	1	5
F	3	3
G	3	5

were fractured at the bonding interface with conditions of 1mm upset or 3mm gap. In the bending test, a no cracks and no broken specimens were observed with combined conditions of 0mm gap and 1mm gap+5mm upset distanse.

Figures 6 and **7** shows the appearance after tensile and bending tests with combined conditions of 1mm gap and 5mm upset distance.

The optical microstructures of the bonding interface in specimen E are shown in **Fig. 8.** It is clear that no defect is oberved and the joint is sound. Scanning electron micrographs of the bonding interface in

Table 4 Results of tensile and bending tests

	Tensile test		Bending test
	Strength (N/mm²)	Fracture portion	
A	466 456 469	Base metal Interface Interface	Good Crack Broken
B	492 503 504	Base metal Base metal Base metal	Good Good Good
C	491 510 505	Base metal Base metal Interface	Good Good Good
D	544 531 537	Base metal Base metal Base metal	Good Crack Broken
E	555 542 540	Base metal Base metal Base metal	Good Good Good
F	549 514 517	Base metal Interface Interface	Good Broken Crack
G	552 539 523	Base metal Base metal Interface	Good Crack Broken

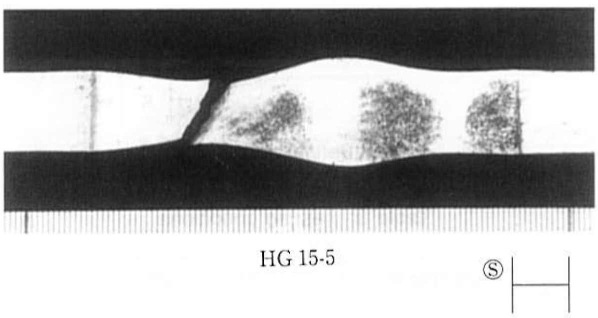


Fig. 6 Appearance after tensile test

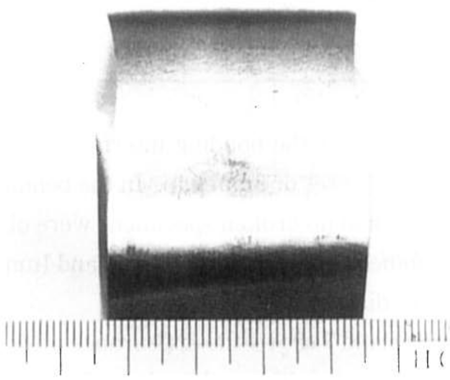


Fig. 7 Appearance after bending test

Fig. 8 Optical microstructure of specimen E

specimens D and F are shown in **Figs. 9** and **10.** From these microstructures, under conditions of large gap and low upset distance, many micro-defects occur in the bonding interface, resulting in poor joint properties. Therefore, the suitable conditions for diffusion bonding of steel H piles is a gap of less than 1 mm and upset distance of more than 5mm.

3.2.2 Full Scale Tension and Compression Tests of Diffusion Bonded Steel H Piles

Diffusion bonding conditions in order to achieve sound joint were clarified by using small specimens. Full scale tests were done in order to evaluate the practical properties.

Figure 11 shows the appearance before full scale testing. Three specimens were tested in full scale tension tests and two specimens were tested in full scale compression tests.

Figures 12 and **13** show the appearance after full

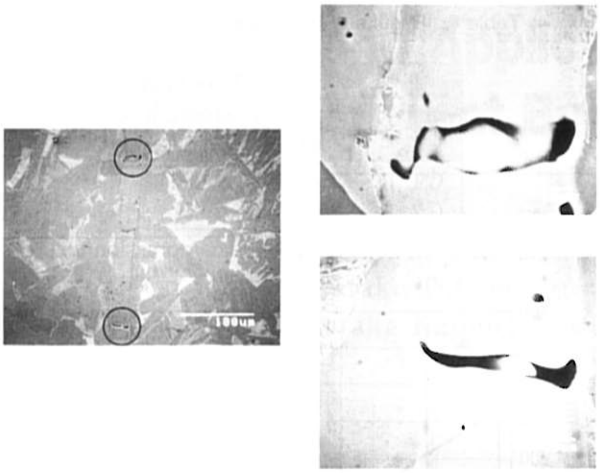
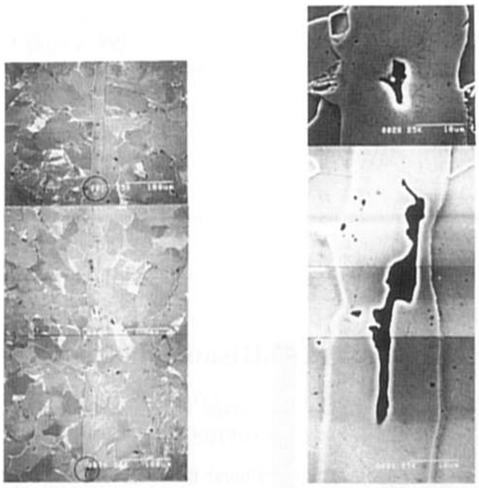


Fig. 9 Scanning electron microstructure of specimen D



(×300) (×3000)

Fig. 10 Scanning electron microstructure of specimen F

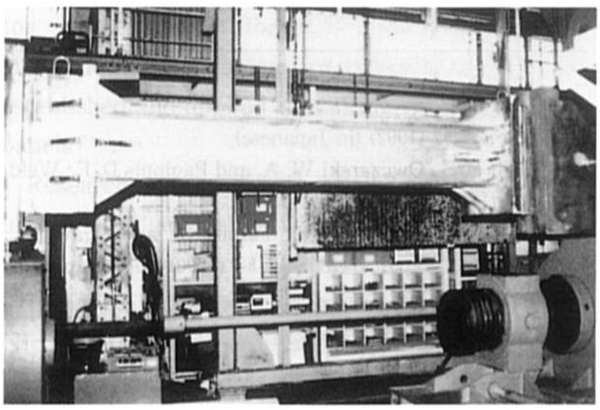


Fig. 11 Appearance before full scale tension test

scale tension and compression tests, and test results are shown in **Tables 5** and **6.** All strengths met the specified strength level. From these results, joint interface is seen to have no problem. Therefore, it is clear that this diffusion bonded joint has excellent practical properties.

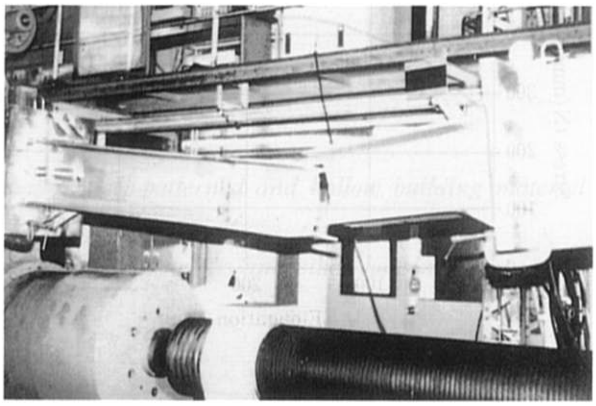


Fig. 12 Appearance after full scale tension test

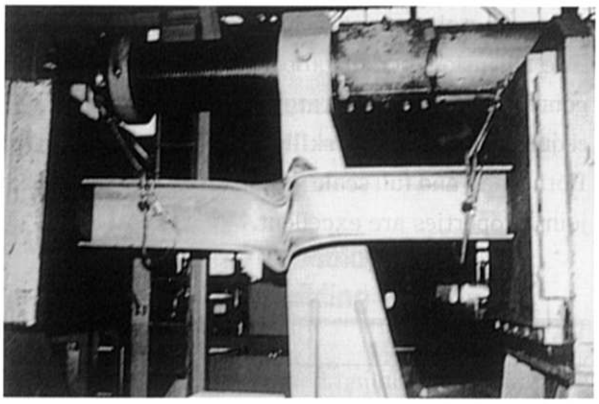


Fig. 13 Appearance after full scale compression test

Table 5 Results of full scale tension test

	Yield strength (N/mm²)	Fractured strength (N/mm²)	Fractured portion	Elongation (%)
T 1	282	432	Base metal	17.8
T 2	283	434	Base metal	18.0
T 3	271	427	Base metal	20.0

Example of S-S curve in full scale tension test (T 2)

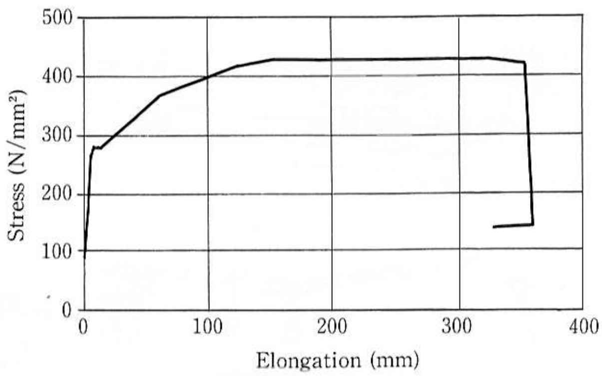
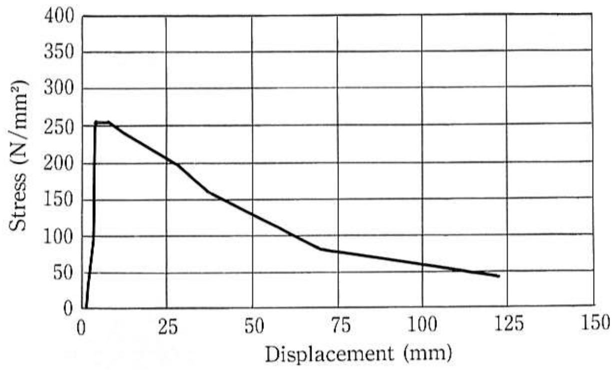


Table 6 Results of full scale compression test

	Yield strength (N/mm²)	Maximum strength (N/mm²)
C 1	258	258
C 2	257	257

Example of S-S curve in full scale compression test (C 1)



4. Conclusions

A diffusion bonding system for joining steel H piles using amorphous metals has been newly developed. The diffusion bonding operation is automatically controlled and the operator of this system does not required any special skills or welding techniques. Both small and full scale specimen tests confirm that joint properties are excellent.

Hisao Iida

Manager, Construction Technology Dept., Tokyo Office

Phone: 03(3282)6274

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