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RECOMMENDATIONS FOR DESIGN AND FABRICATION OF DIFFUSION BONDED JOINTS IN REINFORCING BARS USING AMORPHOUS METAL FOIL

- DRAFT -

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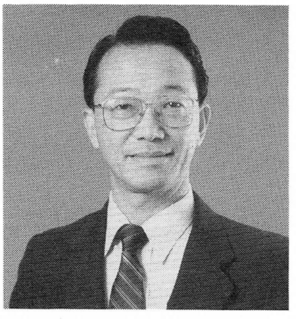
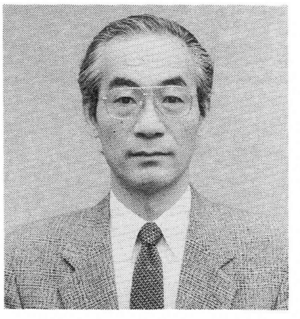
JSCE Research Subcommittee on Diffusion Bonded Joints in
Reinforcing Bars Using Amorphous Metal Foil





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Recommendations for the Design and Fabrication of Diffusion Bonded Joints in Reinforcing Bars Using Amorphous Metal Foil which have been drafted for the first time in Japan, are presented. This is a new joining process which utilizes the principle of diffusion of elements from an amorphous metal foil that is inserted and melted between the ends of the reinforcing bars together with application of pressure. The materials used for joining, design of joints, joining equipment, fabrication and inspection methods, etc. are described.

Keywords: design and fabrication code, reinforcing bar, joining, diffusion bonding, amorphous metal foil

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Preface

At the request of 12 private companies, the Committee on Concrete in the Japan Society of Civil Engineers(JSCE) organized a subcommittee on Joints of Reinforcing Bars. After extensive study and research, the Recommendations for Joints in Reinforcing Bars were proposed and published in Vol. 49 of Concrete International in February 1982. Later, Sumitomo Metal Industries Ltd. and Daido Steel Co. suggested commissioned research on diffusion bonded joints using amorphous metal foil, as such joints had not been included in the specifications regarding the types of joints in the above recommendations. Accepting this suggestion, investigations were commenced by a subcommittee and a secretarial committee established in February 1991.

Diffusion bonding using amorphous metal foil (hereafter referred to as "amorphous metal diffusion bonding") is a joining method developed as a new generation joining technique. It utilizes the diffusion of elements from a thin metal foil that is inserted between the ends of the reinforcing bars and melted by high frequency induction heating together with application of pressure. After inserting the metal foil, processes such as heating, pressure application and holding at the specified temperature, can be performed by automatic control. Due to this reason, high quality joints can be obtained without the need for any particular skill, and variations in joint quality are extremely small.

The methods of fabrication of amorphous metal diffusion bonded joints and the problems of application of this method for joining reinforcing bars were investigated by the subcommittee from several perspectives. In addition, studies were conducted on a number of joints fabricated at site by the two commissioning companies during the period of investigation in order to evaluate the adaptability of this method for on-site fabrication. Since it was confirmed from the results of experiments and from site fabrication investigations that joints of reliable quality are obtained under proper conditions of fabrication, it was decided to publish the results of investigation of the committee as Draft Recommendations for Design and Fabrication.

In the process of formulation of these Recommendations, valuable results were obtained from a large number of experimental studies and applied investigations that were carried out mainly by the two commissioning companies based on the instructions of the committee . For the convenience of actual users, the specifications for design and fabrication as formulated by the two commissioning companies are included separately at the end of these Recommendations as an annex.

I wish to express my grateful thanks to the members of the subcommittee who participated enthusiastically in its activities from beginning to end, and in particular to the members of the secretarial committee and Professor Takeshi Higai, its chairman.

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Chairman
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Reinforcing Bars Using Amorphous Metal Foil
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DRAFT RECOMMENDATIONS FOR DESIGN AND FABRICATION OF DIFFUSION BONDED JOINTS IN REINFORCING BARS USING AMORPHOUS METAL FOIL

Contents

Chapter 1 General

1.1 Scope of applicability

These Recommendations shall apply to the design and fabrication of diffusion bonded joints in reinforcing bars using amorphous metal foil (hereinafter also referred to as "amorphous metal diffusion bonded joints"), for use in general reinforced concrete structures.

The amorphous metal diffusion bonded joint mentioned here is a joint that is obtained by utilizing the principle of diffusion of elements from a thin metal foil that is inserted between the ends of the reinforcing bars and melted by high frequency induction heating together with application of pressure. After inserting the foil, processes such as heating, pressure application, holding at the specified temperature, etc. shall be performed by automatic control.

Matters not specified in these Recommendations shall be ruled by the "Standard Specifications for Design and Construction of Concrete Structures" (hereinafter referred to as "Specifications for Concrete") and the "Recommended Rules for Joints in Reinforcing Bars" (hereinafter referred to as "Recommendations for Joints") of the Japan Society of Civil Engineers(JSCE).

COMMENTARY

These Recommendations set out the standards for the design and fabrication of joints in reinforcing bars (hereinafter also referred to as "bars") in general reinforced concrete structures when diffusion bonding using amorphous metal foil (hereinafter referred to as "amorphous metal diffusion bonding") is employed as the method of joining the bars. Therefore, in the case of designing and fabricating reinforcing bar joints for structures subjected to special loads or special environmental conditions, the matters specified in these Recommendations should be referred to with appropriate consideration being given to the special conditions in the structure concerned.

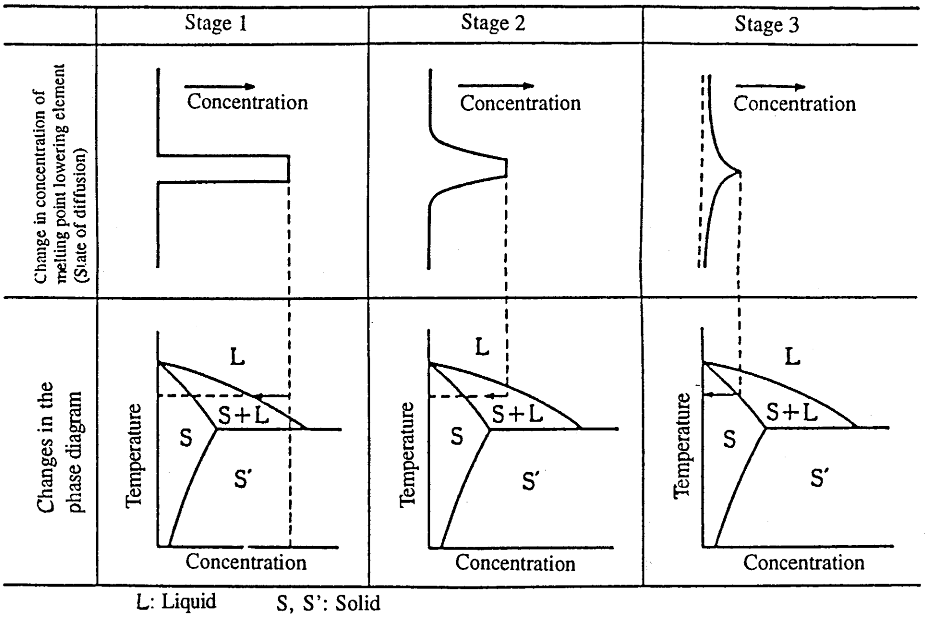
Amorphous metal diffusion bonding is a type of diffusion bonding process that utilizes the diffusion of melting point-lowering elements contained in an amorphous metal foil. Diffusion bonding can be divided into solid state diffusion bonding and transient liquid phase diffusion bonding. Amorphous metal diffusion bonding is a transient liquid phase diffusion bonding process.

Solid state diffusion bonding can be achieved in principle by causing thermal diffusion of atoms to take place between smooth and clean metal surfaces made to come into very close contact with one another so that the inter-atomic distances become small enough for attractive forces to be exerted mutually between the atoms to cause bonding. In actual practice, however, the surfaces to be bonded are uneven microscopically and are also covered by oxide layers. For this reason, it is not easy in actual practice to obtain sound bonded joints by solid state diffusion bonding. In contrast, transient liquid phase diffusion bonding can be achieved with relative ease because the presence of the liquid (molten) metal facilitates the occurrence of atomic scale bonding.

The principle of amorphous metal diffusion bonding using low melting point amorphous metal foils containing boron and other elements that lower the melting point of the metal is illustrated in Fig. 1. In this process, the amorphous metal foil is inserted between the ends of the reinforcing bars which are then fixed in supports. When the joint portion is heated to a temperature just above the melting point of the amorphous metal foil (lower than the melting point of the reinforcing bars) by high frequency induction heating, the amorphous metal foil melts and the molten metal fills the gap between the mating surfaces (Stage 1). During the specified period of isothermal holding at this temperature, the melting point-lowering element (Boron, etc.) diffuses from the molten metal into the base metal, causing its concentration in the molten metal to decrease gradually (Stage 2). As a result of this decrease, the melting point of the molten metal will increase. When the concentration of the melting point-lowering element decreases sufficiently to reach the solidification concentration, the molten metal solidifies and bonding is completed (Stage 3). In other words, amorphous metal diffusion bonding is a type of liquid phase bonding method that utilizes the phenomenon of isothermal solidification caused by the diffusion of melting point-lowering elements contained in the amorphous metal foil. An important characteristic of this bonding method is that high quality joints are obtained since heating, application of pressure and isothermal holding are all carried out and controlled automatically.

These Recommendations are based on investigations carried out regarding the method and equipment for diffusion bonding using amorphous metal foil, and on the results of various tests performed on amorphous metal diffusion bonded joints.

General specifications regarding the design and fabrication of joints in reinforcing bars are stipulated in JSCE's "Standard Specifications for Design and Construction of Concrete Structures" (hereinafter referred to as "Specifications for Concrete") and "Recommended Rules for Joints in Reinforcing Bars" (hereinafter referred to as "Recommendations for Joints"). Therefore, matters not specified in this document shall be ruled by the "Specifications for Concrete" and "Recommendations for Joints".



L: Liquid S, S': Solid

	Stage 1			Stage 2	Stage 3	
Process:	Set	Heat	Hold 1	Hold 2	Hold 3	Cool
Base metal	Solid	Solid	Solid	Solid	Solid	Solid
Amorphous metal	Solid	Solid→Liquid	Liquid	Liquid→Solid+Liquid	Solid+Liquid→Solid	Solid
Phenomenon	-	[Melting of amorphous metal foil] The amorphous alloy melts and fills in the space between the mating surfaces		[Diffusion of melting point-lowering elements (Isothermal solidification)] Due to the diffusion of melting point-lowering elements from the molten metal into the base metal, the melting point of the former is increased and solidification commences		-

Fig. 1 Principle of diffusion bonding using amorphous metal foil
(Isothermal solidification due to diffusion of melting point lowering elements)

1.2 Definitions of terms

The terms used in these Recommendations are defined as follows:

Amorphous metal	: A metal in which the constituent atoms exist randomly and are not arranged in the form of an ordered crystal lattice.
Solid state diffusion bonding	: A joining process utilizing the thermal diffusion of atoms between smooth and clean metal surfaces made to come into very close contact with one another so that the inter-atomic distances become small enough for attractive forces to be exerted mutually between the atoms to cause bonding.
Transient liquid phase diffusion bonding	: A joining process in which the gap between the mating surfaces is filled by molten metal and bonding achieved by diffusion.
Melting point-lowering elements	: Elements that are part of the composition of a metal and have the effect of lowering the melting point of that metal.
Isothermal solidification	: A phenomenon in which, during holding at a constant temperature, a molten metal solidifies due to the concentration of the melting point-lowering element decreasing up to the solidification concentration
Shielding Gas	: A gas used to obtain a non oxidizing joining atmosphere during amorphous metal diffusion bonding.
Wettability	: The ease with which the molten metal spreads on the base metal.
High frequency induction heater	: The equipment used to heat the joint portion by making induction currents to flow in it. This secondary current is induced by a high frequency current flowing through a coil wrapped around the joint portion.
Engineer in charge	: An engineer entrusted with the responsibility for amorphous metal diffusion bonding of reinforcing bars.
Technician	: A person carrying out the operations of amorphous metal diffusion bonding and possessing the necessary Certification of the Japan Pressure Welding Society.

Chapter 2 Materials

2.1 Reinforcing bars

(1)The reinforcing bars to be used for amorphous metal diffusion bonding shall conform to types SR235, SR295, SD295, SD345 and SD390 specified in JIS G 3112 "Steel Bars for Reinforced Concrete", and their diameters shall be between 16mm to 51mm as a general rule.

(2) The reinforcing bars shall possess good joinability with respect to amorphous metal diffusion bonding and shall be free from any defects that may be detrimental to the service of the bars.

COMMENTARY

Regarding (1) above

Other than the types of reinforcing bars specified above, there are others such as SD490 and rerolled steel reinforcing bars (JIS G 3117) that are used for reinforced concrete. However, joints in SD490 have been used little in actual practice currently. As for rerolled steel reinforcing bars, most are small diameters bars (13mm and under) which are not normally used for amorphous metal diffusion bonding. No amorphous metal diffusion bonding has been carried out yet in the case of these bars. For these reasons, SD490 and rerolled steel reinforcing bars have been placed outside the scope of these Recommendations.

The diameters of the reinforcing bars have been specified as 16mm to 51mm based on the experience of actual use up to now. However, bonding of other diameters too may be possible with the equipment available at present. Furthermore, equipment suitable for joining other diameters may be developed in the future. Therefore, amorphous metal diffusion bonding may be carried out in the case of reinforcing bars not specified here provided that the performance of the joints has been confirmed by preliminary tests.

Regarding (2) above

There are usually no conspicuous differences recognizable between the joinabilities of the different types of reinforcing bars specified in JIS G 3112 when amorphous metal diffusion bonding is performed. However, there are cases where surface defects such as cracks, and internal defects such as pipes, segregation, etc. exist. Although these defects have almost no effect on the tensile strength of the base metal, they could cause a decrease in strength of the joints when joining is carried out. Therefore, the reinforcing bars should possess good joinability with respect to amorphous metal diffusion bonding and should be free from any defects that may be detrimental to the service of the bars.

2.2 Amorphous metal foil and shielding gas

(1) As a general rule, the amorphous metal foils used for amorphous metal diffusion bonding shall be nickel base amorphous metal foils.

(2) Shielding gas shall be used when reinforcing bars of diameter 32mm and above are joined. As a standard, the shielding gas shall be nitrogen gas conforming to JIS K 1107.

COMMENTARY

Regarding (1) above

Basically, the type of amorphous metal foil must be selected by considering the type of reinforcing bar and its performance during use. Considering the material of the reinforcing bars to which these Recommendations are applicable, the required joint performance can be obtained even if iron base amorphous metal foils are used as the insert metal. However, since nickel base amorphous metal foils have better wettability compared to iron base ones, the allowable range of surface roughness of the mating surfaces of the reinforcing bars is wider. In addition, nickel base amorphous metal foils show low tendency for corrosion during storage. For these reasons, the use of nickel base amorphous metal foils in principle has been specified.

Nickel base amorphous metal foils contain additions of up to a few % of elements such as boron that lower the melting point of the metal foil. The chemical compositions of the metal foils correspond to those of nickel brazing filler metals specified in JIS Z 3265 and are shown in Table 1.

The standard thickness of the amorphous metal foils should be 25 to 75 μ m. Considering the possibility of misalignment during insertion, its size should be 5 to 10mm larger than the circumference of the reinforcing bars to be joined.

Regarding (2) above

Since oxidation of the amorphous metal surfaces and the reinforcing bar ends will exert detrimental effects on the joinability as the diameters of the reinforcing bars become larger, it is advisable to have a non-oxidizing joining atmosphere. Although non-oxidizing atmospheres can be obtained with argon, helium, etc. as well, these Recommendations specify the use of nitrogen as the shielding gas because of economical considerations. It has been found from previous experience that for diameters of 29mm and less, the joinability is not adversely affected even if shielding gas is not used. Therefore, the use of shielding gas has been stipulated for joints made with reinforcing bars of diameter 32mm and above.

Table 1 Example of chemical compositions of nickel base amorphous metal foils
(From JIS Z 3265 Nickel Brazing Filler Metal)

	Class	B Ni-1	B Ni-1 A	B Ni-2	B Ni-3	B Ni-4	B Ni-5
Chemical Composition (wt.%)	Cr	13.0~15.0	13.0~15.0	6.0~8.0	—	—	18.0~19.5
	B	2.75~3.5	2.75~3.5	2.75~3.5	2.75~3.5	1.5~2.2	0.03 and under
	Si	4.0~5.0	4.0~5.0	4.0~5.0	4.0~5.0	3.0~4.0	9.75~10.5
	Fe	4.0~5.0	4.0~5.0	2.5~3.5	0.50 and under	1.5 and under	—
	C	0.6~0.9	0.06 and under	0.06 and under	0.06 and under	0.06 and under	0.10 and under
	P	0.02 and under	0.02 and under	0.02 and under	0.02 and under	0.02 and under	0.02 and under
	Ni[1)]	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder
	Other elements[2)] total	0.50 and under	0.50 and under	0.50 and under	0.50 and under	0.50 and under	0.50 and under
Reference values	Solidus (℃)	975 approx.	975 approx.	970 approx.	980 approx.	980 approx.	1080 approx.
	Liquidus (℃)	1040 approx.	1075 approx.	1000 approx.	1040 approx.	1065 approx.	1135 approx.
	Brazing temp.(℃)	1065~1205	1075~1205	1010~1175	1010~1175	1010~1175	1150~1205

Notes: 1) Co content of 1.0 or less is allowed
2) 'Other elements' means Pb, etc.

Chapter 3 Design of Joints

3.1 Location of joints

(1) As far as possible, cross sections subjected to high stresses shall be avoided as locations of the joints in the reinforcing bars.

(2) In principle, the locations of the bar joints shall not be concentrated in the same cross section and shall be staggered. The standard distance of staggering shall be 25 times the bar diameter or more.

(3) When the joints cannot be staggered, the allowable stresses for the joints shall be reduced according to Section 9 of the "Recommendations for Fundamentals of Design and Fabrication of Joints in Reinforcing Bars" (hereinafter referred to as "Recommendations for Fundamentals") of the "Recommendations for Joints".

COMMENTARY

Regarding (1) and (2) above

These stipulations have been based on Sections 2 and 9 of the "Recommendations for Fundamentals in Design and Fabrication of Joints in Reinforcing Bars" (hereinafter referred to as "Recommendations for Fundamentals").

Regarding (3) above

The "Recommendations for Joints" are based on the allowable stress design method and are not in the form of the limit state design method of the current "Specifications for Concrete". For applying the allowable stress concept in Section 9(2) of the "Recommendations for Fundamentals", the following approach is suggested.

The reduction of allowable stress when the joints are concentrated in the same section is a measure adopted due to considerations of safety. Therefore, in the event of adopting this to the limit state design method, it will be sufficient to investigate only the ultimate limit state and the fatigue limit state.

In amorphous metal diffusion bonded joints fabricated according to the current Recommendations, if the number of joints in the tension side of same cross section exceeds half the total number of reinforcing bars subjected to tension, it is advised that the allowable design stress be reduced to 90%.

3.2 Spacing of joints

(1) When assembling the reinforcing bars after amorphous metal diffusion bonding, the spacing between a joint and an adjacent joint or bar shall be greater than the largest dimension of the coarse aggregate used in the concrete.

(2) When performing amorphous metal diffusion bonding after assembling the reinforcing bars, spacing that is wide enough to allow installation of the amorphous metal diffusion bonding jig shall be secured in advance.

COMMENTARY

Regarding (1) above

When performing amorphous metal diffusion bonding after assembling the reinforcing bars, the diameter of the joint swelling should in principle be equal to or more than 1.1 times the diameter of the bar in the case of bonding with shielding gas, and be equal to or more than 1.2 times the diameter of the bar in the case of bonding without shielding gas as shown in Section 3.5 below. In specifying the spacing between a joint and an adjacent joint or bar in the current Recommendations as having to be greater than the largest dimension of the coarse aggregate used in the concrete, the specified spacings between bars in locations other than joint locations according to Section 10.6.1 of the "Specifications for Concrete (Design)" have been slightly liberalized. However, since the spaces around the joints are comparatively difficult to fill with concrete usually, it is advisable to allow sufficient leeway when designing the spacing.

Regarding (2) above

When amorphous metal diffusion bonding is to be carried out to join reinforcing bars that cannot be moved to widen the spacing once assembled, it is necessary to secure sufficient spacing by considering the space for assembling of the supporting jig of the pressure application unit on the bars and also the space necessary to introduce the heating coil and carry out the joining operation. The minimum spacings usually required for amorphous metal diffusion bonding are shown in Table 2.

Table 2 Spacing required between reinforcing bar centers for amorphous metal diffusion bonding operations

Nominal size of reinforcing bar	D 16~D 22	D 25~D 29	D32	D 35~D 38	D41	D51
Distance between bar centers(mm)	90	95	100	115	120	145

3.3 Concrete Cover

The concrete cover at the joint portion shall meet the requirements of Section 10.6.1 and 10.2 of the "Specifications for Concrete" (Design)" .

COMMENTARY

The above is based on the requirements of Section 10.6.1 and 10.2 of the "Specifications for Concrete (Design)" .

3.4 Joints of dissimilar steels or of different diameter bars

When bars with widely different diameters, material quality or surface configurations are to be joined by amorphous metal diffusion bonding, testing shall be done in advance to check and confirm the joint performance.

COMMENTARY

In the case of currently available amorphous metal diffusion bonding equipment, the mating surfaces of the reinforcing bars are heated by a heating coil. Because of this, when bars with widely different diameters or surface configurations are to be joined, it is possible to carry out amorphous metal diffusion bonding using the normal conditions of bonding by using a heating coil suited for the purpose. If it is simply a case of different grade of bar or different surface configuration, the bonding conditions or bonding machine need not be specially considered, provided that the material qualities of the bars are not significantly different.

Based on Section 5 of the "Recommendations for Fundamentals", Table 3 shows the possible combination of different diameter bars in the case of joining deformed steel bars. The symbol ◎ indicates the combination of different diameter bars where the ratio of the cross sectional areas is 3/4 or more. In this case, bonding can be carried out using the machine and bonding conditions appropriate for the larger bar. The symbol ○ indicates combinations where the ratio of the cross sectional areas is equal to or more than 1/2 but less than 3/4. In principle, joints can be made with this type of combinations only if the concentration of joints in the same cross section is 1/2 or less. In such cases, if it becomes necessary to adjust the shape of the heating coil, it is recommended that testing be done in advance to check and confirm the joint performance as in the case of joining bars with widely different material quality or surface configurations. Provisions in Sections 5 and 6 of the "Recommendations for Fundamentals" shall apply for matters other than those mentioned above.

From the point of view of joint performance, it is possible to use the amorphous metal foil suited for the smaller diameter bar when joining bars of different diameters. However, considering the ease of inserting the metal foil between the ends of the bars, it is appropriate to use the foil that is suited for the larger diameter bar.

D16	◎									
D19	○	◎								
D22	○	○	◎							
D25		○	◎	◎						
D29			○	○	◎					
D32				○	◎	◎				
D35				○	○	◎	◎			
D38					○	○	◎	◎		
D41					○	○	○	◎	◎	
D51								○	○	◎
	D16	D19	D22	D25	D29	D32	D35	D38	D41	D51

Table 3 Joints made with different diameter bars

Notes ◎ Indicates cross sectional area ratio equal to or more than 3/4
○ Indicates cross sectional area equal to or more than 1/2 but less than 3/4

3.5 Diameter of joint swelling

The diameter of the swelling occurring at the joint portion by upsetting during bonding shall be equal to or more than 1.1 times the diameter of the bar in the case of bonding with shielding gas, and be equal to or more than 1.2 times the diameter of the bar in the case of bonding without shielding gas.

COMMENTARY

In order to improve the safety of the joint, the diameter of swelling occurring at the joint portion by upsetting during bonding was specified to be equal to or more than 1.1 times the diameter of the bar in the case of bonding with shielding gas, and to be equal to or more than 1.2 times the diameter of the bar in the case of bonding without shielding gas.

The maximum diameter of the swelling has not been specified in this section. However, considering the fact that if the swelling is too large, it may interfere with the heating coil and also cause the contraction due to upset to become large, the maximum diameter is usually set at approximately 1.3 times the diameter of the bar in the case of bonding with shielding gas, and at approximately 1.4 times the diameter of the bar in the case of bonding without shielding gas.

Chapter 4 Joining Equipment

4.1 Constitution of the joining equipment
The equipment used for amorphous metal diffusion bonding shall consist of a heating unit to heat the reinforcing bar, pressure applying equipment, a cooling unit, a control unit for controlling the above, other accessories such as cables, and a shielding gas supply unit for use when necessary. The bonding equipment shall be capable of reproducing specified operations repeatedly.

COMMENTARY

One of the characteristics of this method of joining is the stability of joint quality obtained through positive utilization of automatic control. Since joint quality is directly affected by the performance of the bonding equipment, each of the constituent parts of the bonding equipment, their control unit, together with the equipment as a whole, should be checked to confirm that they possess the required capabilities for use in the amorphous metal diffusion bonding operations. The constitution of the amorphous metal diffusion bonding equipment is schematically illustrated in Fig. 2.

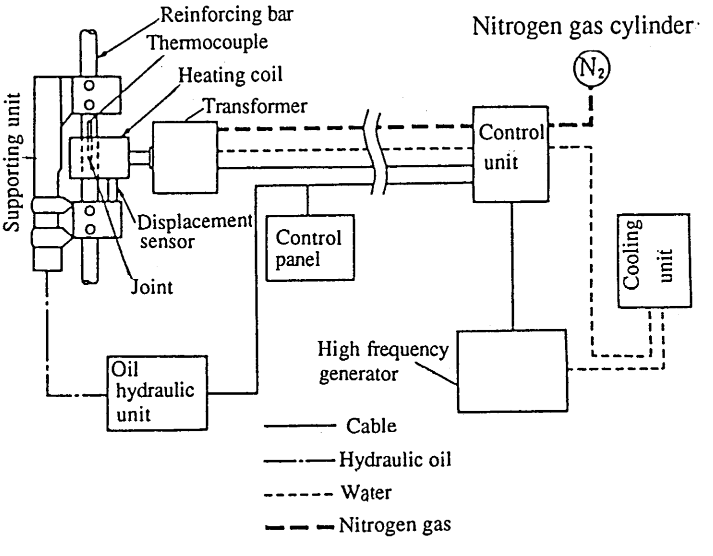


Fig. 2 Example of the constitution of the equipment for amorphous metal diffusion bonding

4.2 Heating unit

(1) The heating unit shall consist of a high frequency generator, transformer, heating coil etc. and a shielding gas supply unit for use when necessary.

(2) The high frequency generator shall possess the capacity necessary to heat the reinforcing bars and shall be capable of smooth variation of power output and frequency.

(3) The transformer shall be capable of changing the voltages and currents generated by the high frequency generator into voltages and currents appropriate for heating the reinforcing bars.

(4) The heating coil shall be constructed so as to be capable of heating the joint portion of the reinforcing bars uniformly and shall be fitted with a cooling mechanism to prevent overheating. In addition, the heating coil shall be fitted with a thermocouple for measuring the temperature of the joint and, when necessary, shall be provided with a shielding gas supply unit to allow a non-oxidizing atmosphere to be maintained inside the heating coil.

(5) The pressure regulator and gas hoses used for shielding gas supply shall have the capacity to allow the required gas flow rates and shall be constructed with due consideration for safety.

(6) The heating unit shall be capable of heating the joint to the bonding temperature of 1250±50 ℃ and maintaining the joint at this temperature for at least 120 seconds. In addition, it shall be capable of automatic operation under commands received from the control unit.

COMMENTARY

Regarding (1) to (6) above

The basic configuration of the heating unit is shown in Fig. 3 and examples of its specifications in Table 4. Since the coaxial cable connecting the transformer to the heating coil can be extended (up to 70m approximately), it is possible to carry only the heating coil and transformer to the joining site and carry out the bonding operations.

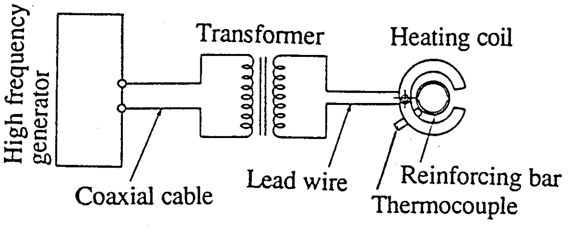


Fig. 3 Basic configuration of the heating unit

Table 4 Range of heating unit specifications and examples of specifications according to reinforcing bar diameter

Equipment	Specifications		D29	D51
High frequency generator	Output power (kW)	5 ~ 50	10	50
	Input voltage (V)	200 / 220	200 / 220	200 / 220
	Input capacity (kVA)	8 ~ 75	12	75
	Frequency (kHz)	2 ~ 30	15	5
Transformer	Capacity (kVA)	50 ~ 250	50	250
	Frequency (kHz)	2 ~30	15	5
Heating coil	Coil width (mm)	20 ~ 50	30	30
	Thermocouple	Provided	Provided	Provided
	Shielding mechanism *	Provided	Not provided	Provided
Shielding gas supply unit *	Shielding gas	Nitrogen	-	Nitrogen
	Flow rate (l/min)	100 ~ 150	-	100 ~150

* : Used when necessary

4.3 Pressure applying equipment

(1) The pressure applying equipment shall consist of a supporting unit and a pressure application unit.

(2) The supporting unit shall be capable of gripping and supporting the reinforcing bars with sufficient force, be easy to handle and shall be provided with a mechanism to ensure that axial misalignment or bending does not occur at the joint. Furthermore, the jig that supports and grips the bars shall be shaped to prevent any damage to the bar surfaces.

(3) The pressure applying equipment shall be capable of applying a force in the direction of the reinforcing bar axis during the bonding operations. Its capacity shall be such that a pressure of at least 30MPa can be applied with respect to the cross section of the bars and it shall also possess the capability of imparting the specified amount of upset (contraction) to the bars.

(4) The pressure applying equipment shall be capable of automatic operation under commands received from the control unit.

COMMENTARY

Regarding (1) above

The basic configuration of the pressure applying equipment is illustrated in Fig. 4

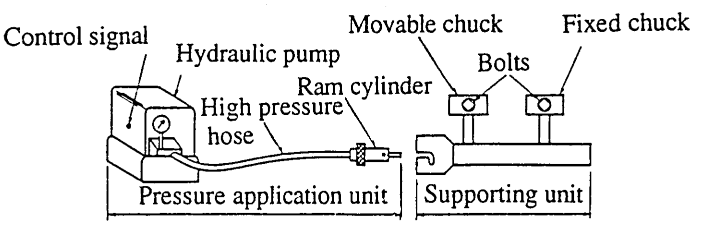


Fig. 4 Basic configuration of the pressure applying equipment

Regarding (2)above

In order to obtain a sound joint, it is necessary to support the two reinforcing bars to be joined firmly by a supporting unit having a mechanism that prevents axial misalignment and bending. Also, the ends of bolts of the supporting unit that are used to grip the bars should be suitably shaped to prevent the occurrence of any damage to the bars that may affect the joint strength.

Regarding (3) and (4) above

The pressure applying equipment consists of an electrical hydraulic pump that is operated by commands from the control unit, a ram cylinder and high pressure hoses.

The temperature of the joint portion and the applied pressure are extremely important factors for obtaining sound quality joints. It has been established thorough experimental investigations that for joint temperatures in the range 1250±50℃, the joinability is good if the applied pressure is 30MPa or higher. Therefore, it has been stipulated that the pressure applying equipment be capable of applying pressures of 30MPa or higher so as to match the heating unit specifications in Section 4.2. It has also been stipulated that the pressure applying equipment be provided with a mechanism enabling the required amount of upset (contraction) to the bars. The amount of upset is 6mm or more in the case of shielding gas being used, and equal to or greater than 1/4th the bar diameter in the case of no shielding. It must be noted that if slipping of the bar on the supporting unit occurs or if leakage occurs in the pressure applying equipment, the required pressure cannot be achieved. Therefore it is important to check for such phenomena.

4.4 Cooling unit

(1) The cooling unit shall possess a mechanism to supply sufficient cooling water for preventing overheating of each component of the heating unit.

(2) The cooling unit shall be additionally provided with equipment for maintaining the temperature of the cooling water below a specified value when necessary.

COMMENTARY

Regarding (1) above

Very large currents flow in the heating unit (High frequency generator, Transformer and Heating coil). Cooling water is necessary as a preventive measure against the risk of damage to heating unit by overheating and melting due to insufficient cooling. The cooling unit should be capable of allowing the pressure, temperature, flow rate, etc. of the cooling water to be set at required values. In addition, it should also be provided with a mechanism that prevents overheating even under conditions of insufficient pressure and flow rate or if the water flow gets cut-off.

Regarding (2) above

Because the cooling water is usually recirculated during operations at site, its temperature will tend to rise as joining is performed repeatedly. Moreover, high atmospheric temperatures during summer will also contribute toward the temperature rise of the cooling water and there is a possibility that the specified cooling water temperature is exceeded due to these factors. In such cases, either additional equipment should be provided to reduce the cooling water temperature or the commencement of joining operations should be delayed until the cooling water temperature has fallen to the required level.

The specified cooling water temperature is the limiting temperature necessary to prevent overheating and is usually 32℃.

4.5 Control unit

(1) The control unit shall be one that is capable of allowing the setting of the joining conditions appropriate to the diameters of the reinforcing bars to be joined.

(2) The control unit shall possess the capability to allow automatic control of the joining operations by controlling the heating unit, pressure applying equipment, cooling unit and the shielding gas supply unit according to preset joining conditions.

COMMENTARY

Regarding (1) above

The control unit has been specified as one that possesses the mechanism to allow the appropriate joining conditions such as bonding temperature, high frequency generator output, high temperature holding time, etc. to be set according to the diameter of the reinforcing bars to be joined. The appropriate joining conditions are shown in Table 5. It should be noted that these conditions apply to bonding equipment currently available, and may change in the future as a result of improvements and changes to the bonding equipment.

Regarding (2) above

The control unit should possess the capability to allow joining to be carried out automatically by controlling the undermentioned parameters according to the sequence illustrated in Fig. 5.

- ●Bonding temperature .... The power output of the high frequency generator is controlled so as to obtain the heating pattern shown in Fig. 5 and to maintain constant temperature during the holding period.
- ●Temperature holding period ... After the joint has reached the specified temperature, the period for which this temperature is maintained constant is controlled.
- ●Pressure application .... After the joint has reached the specified temperature, pressure is controlled and applied intermittently until the specified amount of upset is achieved.
- ●Shielding gas supply .... Shielding gas flow commencement and cut-off commands are generated when shielding gas is employed.

In addition to the above, the control unit should possess the capability to allow a said operation to be reproduced repeatedly.

Table 5 Appropriate bonding conditions

	With shielding	Without shielding
Bonding temperature	1250±50°C	1250±50°C
Holding time	120s or longer	120s or longer
Upset (contraction) distance	6mm or more	1/4×Diameter of bar or greater

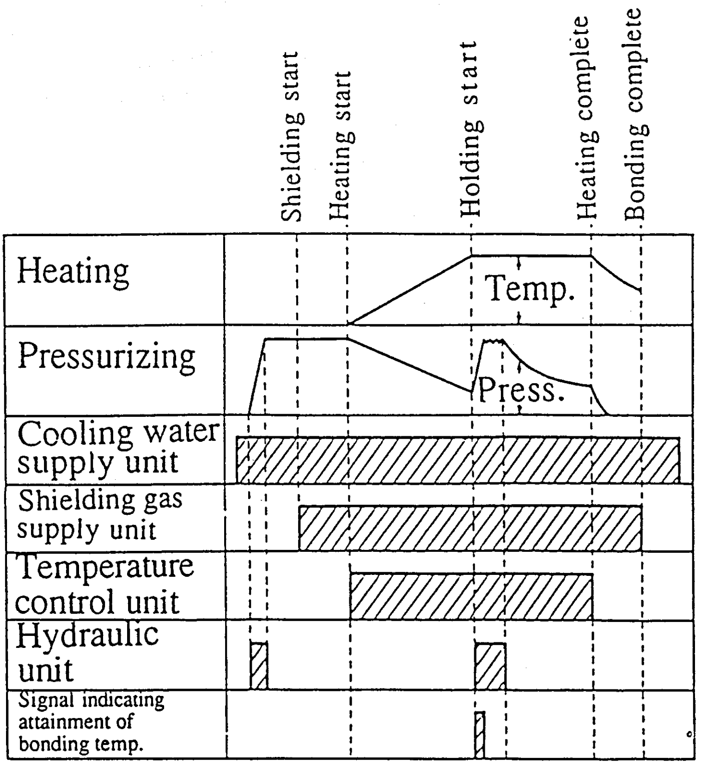


Fig. 5 Basic control sequence

Chapter 5 Fabrication

5.1 Operators for amorphous metal diffusion bonding

(1) Persons carrying out amorphous metal diffusion bonding shall belong to one of the undermentioned categories, (a) or (b).

(a) A person who has acquired Class I or higher certification as a qualified manual gas pressure welding technician under the Japan Gas Pressure Welding Society's standard qualification and certification procedure for manual gas pressure welding technique, and has also followed successfully the training program held by the Japan Gas Pressure Welding Society on amorphous metal diffusion bonding.

(b) A person who has been certified as an amorphous metal diffusion bonding technician under the Japan Gas Pressure Welding Society's standard qualification and certification procedure for high frequency pressure welding with amorphous metal foil.

(2) Any person assisting the amorphous metal diffusion bonding operations shall be one who has the necessary knowledge about and experience in amorphous metal diffusion bonding or gas pressure welding.

COMMENTARY

Regarding (1) above

Since the technician performing amorphous metal diffusion bonding must have sufficient knowledge about the process and possess the skill to manipulate the bonding equipment correctly, it has been stipulated that he or she should belong to one of the undermentioned categories, (a) or (b).

Those belonging to category (a):

Basic operations of amorphous metal diffusion bonding such as processing of the reinforcing bars, treatment of its end faces and assembling on the supporting unit, are similar to those carried out in gas pressure welding. Those persons who have qualified as gas pressure welding technicians under Japan Gas Pressure Welding Society's qualification and certification procedures have sufficient proficiency in these basic operations. Because of this reason, it has been specified that it would be sufficient qualification for technicians performing amorphous metal diffusion bonding to possess Class I or higher certification as a qualified gas pressure welding technician. However, it has been additionally stipulated that even if possessing certification a qualified gas pressure welding technician, the technician performing amorphous metal diffusion bonding should have also successfully followed the training program held by the Japan Gas Pressure Welding Society on amorphous metal diffusion bonding. The reason for this is that the technician carrying out amorphous metal diffusion bonding needs to possess general knowledge of the process and the skill to manipulate and operate the amorphous metal diffusion bonding equipment correctly.

Those belonging to category (b):

A person who has been certified as an amorphous metal diffusion bonding technician under the Japan Gas Pressure Welding Society's standard qualification and certification procedure for high frequency pressure welding with amorphous metal foil may work as the technician for amorphous metal diffusion bonding.

The fabricator should obtain prior approval for carrying out the amorphous metal diffusion bonding operations by submitting the name and photograph of each technician employed together with copies of their certificates of qualification as amorphous metal diffusion bonding technician, or together with copies of their certificates of qualification as gas pressure welding technician and those of completion of training program on amorphous metal diffusion bonding. The technicians should carry these certificates on their person at all times.

Regarding (2) above

The quality of the joint is affected by the condition of the end faces of the reinforcing bars and by the manner in which the bars are assembled and set on the supporting unit. Therefore it has been stipulated that the assistants who perform these operations should have knowledge about and experience in amorphous metal diffusion bonding or gas pressure welding.

> **5.2 Processing of reinforcing bars**
>
> (1) The reinforcing bars shall be cut or otherwise processed so that the length after joining corresponds correctly to the length specified in the design drawings. The allowance for contraction in length of the bars due to upset shall be estimated as being approximately 20 to 30% of the bar diameter per joint.
>
> (2) As a principle, the bars shall be cut by mechanical means and the surface roughness of the ends of the bars shall be 100 μ m or less. The mating surfaces shall be nearly perpendicular to the longitudinal axis of the bar. Particular care shall be taken to avoid any bending occurring at the bar ends.

COMMENTARY

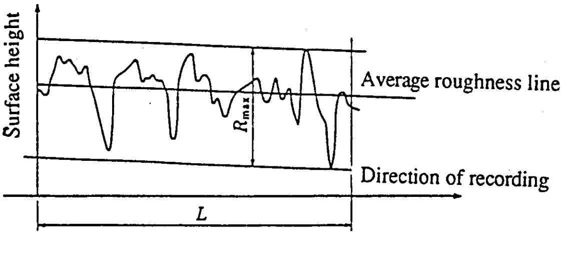
Regarding (1) above

Since the reinforcing bars are upset by the applied pressure and swelling occurs at the joint, the length of the bars is shortened after joining by about 20 to 30% of the bar diameter. Therefore, the bars should be cut with due allowance being given to the above amount of contraction occurring at each joint.

Regarding (2) above

For obtaining the best joint quality, the mating surfaces should be smooth, be perpendicular to the reinforcing bar axis and there should be no gap between them. Therefore it has been stipulated that the bars be cut using mechanical cutters such as high speed disc cutters. Also, the roughness (R_{max}) of the mating surfaces has been specified as having to be 100 μ m or less since it has been found by the experience up to now that good quality joints are obtained in this case. (See Fig. 6).

The measurement of roughness should be in accordance with JIS B 0601 "Surface roughness - Definitions and designation", but boundary samples may be used instead. If gas cutting is used for unavoidable reasons, the cut surfaces should be made smooth, and scale, slag, etc. should be removed. In such a case, joining should be carried out after checking and confirming that the gap between the mating surfaces satisfies the specified value



L : Standard Length
Rmax : Maximum height of sampled surface with respect to the standard length

Fig. 6 Definition of roughness (R_{max}) of the mating surfaces

5.3 Bonding operation

The bonding operations shall be performed properly in accordance with the fabrication specifications using the specified amorphous metal diffusion bonding equipment. In formulating the fabrication specifications, care shall be taken regarding the following: (1) that the amorphous metal foil is stored and handled in a suitable manner, (2) that cutting and other processing of the reinforcing bars are carried out on the day of the bonding operation, (3) that the gap between the mating surfaces of the reinforcing bars is 3mm or less, (4) that the axial misalignment between the bars is equal to or less than 1/10th the bar diameter or 4mm, whichever is smaller, and (5) that the misalignment between the crown of the swelling formed by bonding and the joint plane be equal to or less than 1/4th the bar diameter.

COMMENTARY

Before commencing joining, detailed fabrication specifications should be formulated and the fabrication should be performed properly in accordance with these specifications. In determining the fabrication specifications, the following points should be taken into careful consideration.

(a) Checking and maintenance of bonding equipment and use of proper power supply

Maintenance of the equipment and accessories should be carried out properly in order to prevent bonding defects that may occur due to malfunctions in the pressure applying equipment, heating unit, control unit, etc. or due to instability in the electric power supply.

(b) Storage of amorphous metal foils

The amorphous metal foils should always be stored in a dry place and be dried if necessary in a drier before use.

(c) Gap between mating surfaces

Oil, grease, cement paste, rust, mud, etc. which have adhered on the reinforcing bars within a distance of about 50 to 100mm from its ends should be removed before commencing joining operations and the end faces should always be finished smooth by grinding on the day of the joining.

It has been specified that the gap between the mating surfaces should be 3mm or less when the bars are fixed in position in the supporting unit since experience up to now has shown that sound joints are obtained in such cases. (See Fig. 7).

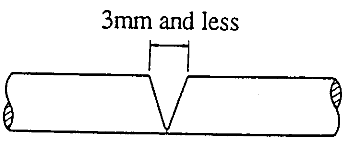


Fig. 7 Gap between mating surfaces

(d) Axial misalignment of the reinforcing bars

Since sound joints can be obtained if the axial misalignment between the reinforcing bars is equal to or less than 1/10th the bar diameter or 4mm, whichever is smaller, it has been specified that the bars and the supporting unit be adjusted so that the axial misalignment is smaller than the above mentioned values. (See Fig. 8).

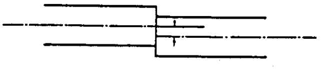


Fig. 8 Axial misalignment

(e) Setting of the amorphous metal foil

The amorphous metal foil should be set between the mating surfaces immediately before joining as a general principle. Any oil, grease, rust, etc. adhering on the foil should be removed beforehand. When inserting the amorphous metal foil, great care should be taken to ensure that it is set properly between the two mating surfaces of the reinforcing bars. Heating should be commenced only after ascertaining that the foil has not slipped or moved after setting. If the setting is found to be improper, the foil should be removed and reset properly.

(f) Setting of the heating coil

When assembling the heating coil over the joint portion after setting the amorphous metal foil, it should be confirmed that the heating coil is coaxial with the reinforcing bars. Also, the heating coil and supporting unit should be adjusted so that the center of the heating coil is in line with the joint plane. (See Fig. 9).

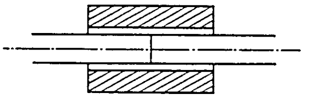


Fig. 9 Location of heating coil

With due consideration to the width of the heating coil, the amount of misalignment between the crown of the swelling formed after bonding and the joint plane has been specified as having to be equal to or less than 1/4th the bar diameter.

(g) Weather

Operations under conditions of rainfall, snowfall or wind should be carried out under the following restrictions:

① Operations should not be performed if water drops due to rain or snow adhere onto or if water flows in and wets the mating surfaces. Joining may be performed if reliable shielding is provided to avoid the above.

② Since winds are liable to disturb the shielding gas within the heating coil and cause non-uniformity in the temperature of the heated reinforcing bars, defects may occur in the joint. Because of this reason, the wind speed at the joint should be confirmed to be 10m/s or lower. If the wind speed exceeds this value, sheet covering, etc. should be erected so as to reduce the wind speed at the joint.

(h) Measures to be taken when heating is interrupted

If heating is interrupted during joining, that portion of the joint should be cut off and the joining should be re-performed.

(i) Safety and accident prevention

① The joining operations should be done with full care to ensure safety in accordance with the Ordinance of Industrial Safety and Hygiene, Pressurized Gas Control Law and other related regulations.

② Appropriate protection measures should be taken if there is a risk of inflammable material in the vicinity catching fire or being damaged by ignition by the sparks generated by grinding, etc.

③ As the amorphous metal foil is sharp at the edges, care should be taken against injury to the persons handling it. Any remaining unused metal foils and cut pieces should be recollected.

Chapter 6 Inspection

6.1 Inspection before fabrication

Before fabricating the joints, test specimens of the joint shall be fabricated at the fabrication site or at a place where the conditions are the same as those at the fabrication site, using the same type of reinforcing bars and the same bonding conditions intended to be used during actual site fabrication. The test specimens shall be inspected in accordance with the stipulations mentioned below in Section 6.3: Visual inspection, Section 6.4: Non destructive inspection and Section 6.5: Destructive inspection. It shall be confirmed that there is no malfunctioning of the bonding equipment, that the bonding conditions are appropriate and that sound quality welds are obtained.

COMMENTARY

In amorphous metal diffusion bonding, equipment malfunction or the use of inappropriate bonding conditions may lead to abnormal joint shape, dimensions, surface condition, etc. and result in a reduction in the joint strength. Therefore it is stipulated that before actual fabrication, test joints shall be made in order to confirm that there is no equipment malfunction and that the bonding conditions used are proper. In this case, the number of test specimens made shall be two.

All test specimens should satisfy the visual inspection, non destructive inspection and destructive inspection specifications of Sections 6.3, 6.4 and 6.5, respectively. If the results of inspection are unsatisfactory, the cause should be clarified according to the flow chart shown in Fig. 10 and reinspection should be carried out using test specimens fabricated after the necessary rectification of the bonding equipment and correction the bonding conditions.

Inspection before fabrication

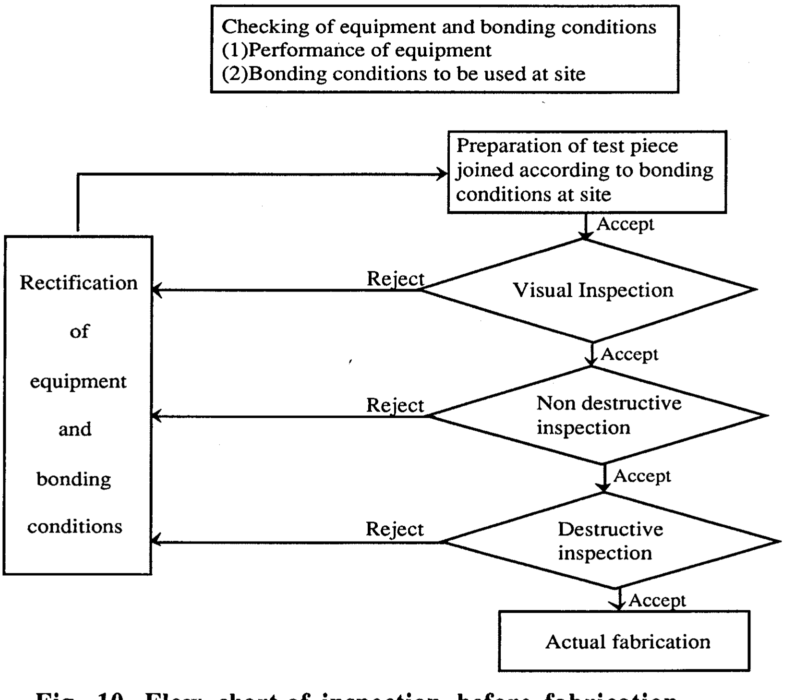


Fig. 10 Flow chart of inspection before fabrication

6.2 Inspection at the time of fabrication

(1) Inspection at the time of fabrication shall consist of visual inspection and non destructive inspection.

(2) Visual inspection shall be performed according to Section 6.3 with 100% sampling.

(3) Sampling inspection of lots shall be performed by the method of non destructive inspection specified in Section 6.4.

The number of joints inspected in this case shall be decided at the discretion of the engineer in charge. If a lot is rejected as a result of the sampling inspection, all the joints of the lot shall be subjected to non destructive inspection according to Section 6.4.

(4) Disposal of joints that are rejected by visual inspection or non destructive inspection shall be carried out according to the instructions of the engineer in charge.

COMMENTARY

Regarding (1) above

Inspection of the joints at the time of fabrication shall consist of visual inspection and non destructive inspection. Tensile testing is carried out in case of rejection by visual inspection or non destructive inspection in order to clarify the cause of the defect. The standard flow chart of inspection is shown in Fig. 11 and it is advised that this flow chart be followed at the time of fabrication.

Inspection at the time of fabrication

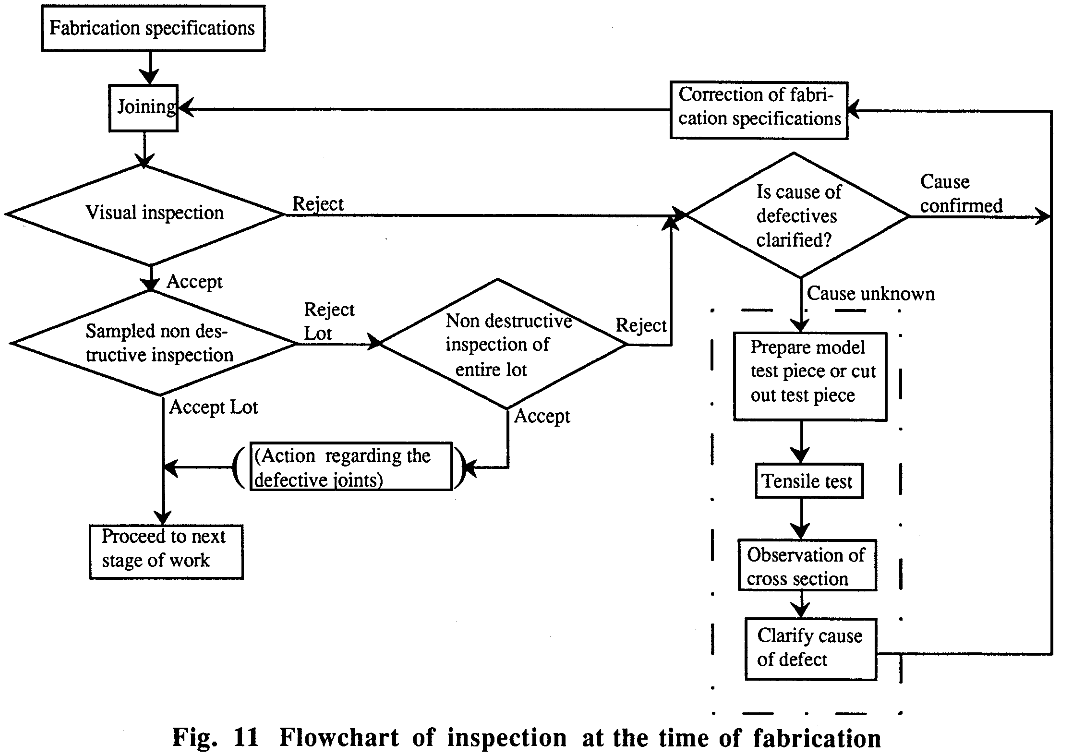


Fig. 11 Flowchart of inspection at the time of fabrication

Regarding (2) above

All amorphous metal diffusion bonded joints should be inspected visually. The method of visual inspection should conform to the provisions of Section 6.3.

Regarding (3) above

The sampling rate is usually 10% or more and should be decided by the engineer in charge with due consideration to the importance of the structure, inspection results, etc. In principle, an inspection lot shall be made up of joints fabricated by the same group of workers. The method of non destructive inspection should conform to the provisions of Section 6.4.

Table 6 shows an example of the sampling rate and acceptance criteria for ultrasonic flaw detection testing of gas pressure welded reinforcing bar joints as specified by the Japan Highways Public Corporation, Metropolitan Expressway Public Corporation and East Japan Railways Co. It is recommended that this table be taken as a reference when formulating the plans for fabrication and inspection.

Regarding (4) above

If a joint is rejected by visual inspection or non destructive inspection and the reason for such rejection cannot be established, the joint strength should be checked by tensile testing according to the instructions of the engineer in charge. In such cases, the tensile test may be carried out using a model specimen fabricated by the same workers, employing the same materials and equipment used for fabricating the defective joint, or by cutting off the rejected joint and using it as the tensile test specimen. The model specimen is used when it is believed that the reason for rejection is lies mainly with problems in the bonding equipment or bonding conditions. The cut off specimen is used when it appears that the reason for rejection lies mainly with problems in the bonding operation. There may be cases when both types of specimens are used depending on the judgment of the engineer in charge. The tensile test should be performed in accordance with Section 6.5. Disposal of joints rejected by visual inspection or non destructive inspection should be carried out according to the instructions of the engineer in charge.

Table 6 Examples of sampling quantity for ultrasonic inspection of gas pressure welded joints and the acceptance criteria for inspection lots

Organization formulating the standard	Inspection lot	No. of samples	No. for judging acceptance	Accept/ Reject criterion
Japan Highways Public Corporation	Joints bonded under the same conditions in the same type of structural member	30 Nos.	1 Location	-24dB
Metropolitan Expressways Public Corporation	Joints made by the same worker group in one day	50%	1 Location	-27dB
East Japan Railways Co.	Joints made by the same worker group in one day	50%	1 Location	-24dB

6.3 Visual inspection of joints

(1) Visual inspection shall be carried out by observing the joint appearance visually and by using vernier calipers, measuring scale etc.

(2) During visual inspection, the melting and solidification of the amorphous metal foil shall be confirmed and the swelling due to upset shall be checked for proper dimensions and shape as well as for the presence of any damage or defects.

(3) The diameter of the swelling shall be equal to or larger than 1.1 times the diameter of the reinforcing bar when shielding gas is used, and equal to or larger than 1.2 times the diameter of the reinforcing bar when no shielding gas is used. Axial misalignment shall be equal to or less than 1/10th the bar diameter or 4mm, whichever is smaller. The misalignment between the crown of the swelling and the joint plane shall be equal to or less than 1/4th the bar diameter. In addition, no noticeable bending shall be present.

COMMENTARY

Regarding (1) above

Visual inspection should be carried out with respect to 100% of the joints. Joints where irregularities in shape are observed should be checked for proper dimensions using vernier calipers, measuring scale, etc.

Regarding (2) above

Since the amorphous metal foil is larger than the reinforcing bar cross section, a part of it will lie outside the periphery of the bars. During bonding, it will melt, solidify and adhere onto the bar surfaces in the vicinity of the joint. If such adherence of metal is not observed, the soundness of the joint should be confirmed by non destructive inspection according to Section 6.4.

Regarding (3) above

The diameter of the swelling due to upset, the axial misalignment and the misalignment between the crown of the swelling and the joint plane are important control factors with respect to the safety and soundness of the joints. The values specified here have been chosen on the basis of experimental results and actual joint performance.

6.4 Non destructive inspection of joints

Non destructive inspection of the joints shall be carried out by ultrasonic flaw detection according to JIS Z 3062 "Method of Ultrasonic Examination for Gas Pressure Welds in Reinforcing Deformed Bars".

COMMENTARY

Although JIS Z 3062 "Method of Ultrasonic Examination for Gas Pressure Welds in Reinforcing Deformed Bars" applies to gas pressure welded joints in reinforcing bars, it was confirmed through the results of various tests that the same method of ultrasonic testing and acceptance criteria are applicable to amorphous metal diffusion bonded joints as well. The above test method was adopted for amorphous metal diffusion bonded joints for this reason.

6.5 Destructive inspection of joints

Destructive inspection of the joints shall be carried out by tensile testing. The tensile strength of the joint shall satisfy Class A strength in Section 3(1) Static strength, specified in the recommendations for evaluation of reinforcing bar joints of the "Recommendations for Joints".

COMMENTARY

Destructive inspection is carried out for the purpose of overall confirmation of the suitability of the equipment, conditions and operations used for amorphous metal diffusion bonding. Destructive inspection should be performed by tensile testing of the joint as bonded. The tensile test should be performed in accordance with JIS Z 2241 "Method of Tensile Test for Metallic Materials", subject to the condition that the cross sectional area used for calculating the tensile strength be the nominal cross section specified in JIS G 3112 "Steel Bars for Concrete Reinforcement".

For the destructive inspection specified in Section 6.1, the number of test specimens should be 2. For acceptance in the tensile test, it is necessary that both specimens satisfy Class A strength in Section 3(1) Static strength, specified in the recommendations for evaluation of reinforcing bar joints of the "Recommendations for Joints", and the rupture should occur in the base metal.

Draft Specifications for Fabrication of Diffusion Bonded Joints in Reinforcing Bars Using Amorphous Metal Foil

Contents

Please note that this document is a translation from Japanese. The original Japanese language document has priority over this English edition if any controversy arises regarding their contents.

Draft Specifications for Fabrication of Diffusion Bonded Joints in Reinforcing Bars Using Amorphous Metal Foil

1. Scope of applicability

These Specifications shall be applicable to the fabrication of diffusion bonded joints using amorphous metal foil (hereinafter referred to as "amorphous metal diffusion bonded joints")* in type SR 235, SR 295, SD 295, SD345 and SD390 reinforcing bars specified in JIS Z 3112 "Steel Bars for Concrete Reinforcement".

* Diffusion bonded joints using amorphous metal foil (amorphous metal diffusion bonded joints) are those obtained by utilizing the diffusion of elements from an amorphous metal foil inserted between the ends of the reinforcing bars and melted by heating the joint portion using a high frequency induction furnace. Bonding is achieved by holding the joint portion at a specified temperature for a given period of time with application of pressure in the axial direction of the reinforcing bars.

2. Equipment

The specifications of the equipment used for amorphous metal diffusion bonding are given below.

(1) Electric power source

The electric power source shall be capable of supplying the necessary power to the high frequency generator, pressure applying equipment, cooling unit, etc. If commercial electric power supply is unavailable, an engine driven AC generator (JEM1398 Diesel engine driven portable type AC generating equipment) shall be used.

The electric power source secured shall have sufficient capacity to satisfy the total power requirement of the high frequency generator, pressure applying equipment, cooling unit, etc.

(2) Bonding Equipment

The equipment used for amorphous metal diffusion bonding shall consist of a heating unit to heat the reinforcing bars, pressure applying equipment for pressure application to the bars, a control unit for controlling the above, a cooling unit for preventing overheating of the high frequency generator heating coil etc., a shielding gas supply unit for maintaining a non-oxidizing atmosphere around the joint portion when necessary, and other accessories such as cables, etc. The bonding equipment shall be capable of reproducing specified operations repeatedly.

① Heating unit

(i) The high frequency generator shall possess the capacity necessary to heat the reinforcing bars and shall be capable of smooth variation of power output and frequency.

(ii) The transformer shall be capable of changing the voltages and currents generated by the high frequency generator into voltages and currents appropriate for heating the reinforcing bars.

(iii) The heating coil shall be constructed so as to be capable of heating the joint portion of the reinforcing bars uniformly and shall be fitted with a cooling mechanism to prevent overheating. In addition, the heating coil shall be fitted with a thermocouple for measuring the temperature of the joint and, when necessary, shall be provided with a shielding mechanism that allows a non-oxidizing atmosphere to be maintained in the vicinity of the joint portion.

(iv) In order to prevent interference due to electromagnetic leakage, the high frequency generator casing and the secondary side cables shall be shielded and earthed properly.

② *Pressure applying equipment*

(i) The pressure applying equipment shall consist in principle of a supporting unit and a pressure application unit.

(ii) The supporting unit shall be capable of gripping and supporting the reinforcing bars with sufficient force, be easy to handle and shall be provided with a mechanism to ensure that axial misalignment or bending does not occur at the joint. Furthermore, the jig that supports and grips the bars shall be shaped to prevent any damage to the bar surfaces.

(iii) The pressure applying equipment shall be capable of applying a force in the direction of the reinforcing bar axis during the bonding operations. Its capacity shall be such that a pressure of at least 30MPa can be applied with respect to the cross section of the bars and it shall be possible to maintain the pressure that has been set for the necessary length of time.

(iv) In principle, the pressure applying unit shall possess the capability that makes it possible for the pressure force for bonding to be secured.

(v) The pressure applying equipment shall be capable of automatic operation under commands received from the control unit.

(vi) The amount of upset shall be automatically produced under the command received from the control unit.

③ *Control unit*

(i) The control unit shall be one that is capable of allowing the setting of the joining conditions appropriate to the diameters of the reinforcing bars to be joined.

(ii) The control unit shall possess the capability to allow automatic control of the joining operations by controlling the heating unit, pressure applying equipment, cooling unit and the shielding gas supply unit according to preset joining conditions.

④ *Cooling unit*

(i) The cooling unit shall possess a mechanism to supply sufficient cooling water for preventing overheating of each component of the heating unit.

(ii) The cooling unit shall possess flow switches or other mechanisms that will effectively prevent overheating of the high frequency generator and heating coil due to cut off of water supply or due to decrease in the flow rate or pressure of the cooling water.

(iii) The cooling unit shall be provided with a mechanism such as a cooler, etc. for maintaining the temperature of the cooling water below a specified value if necessary.

3. Matters for consideration in joint design and fabrication

(1) Spacing between reinforcing bars

It is advised that the spacing between the reinforcing bars be equal to or greater than the values shown in Table 1.

(2) Height of joints and working space

In general, for horizontal reinforcing bars the height of the joint above the floor shall be equal to or greater than the reinforcing bar center to center spacing shown in Table 1, and for vertical bars it shall be 400mm or greater. If there are walls or other obstructions on the side at which the bonding equipment is to be assembled, it is advisable to secure a spacing of at least 800mm between the bars (central axes).

Table 1 Spacing required between reinforcing bar centers

Nominal size of reinforcing bar	D 16~D 22	D 25~D 29	D32	D 35~D 38	D41	D51
Distance between bar centers(mm)	90	95	100	115	120	145

(3) Reinforcing bars suited for bonding

Amorphous metal diffusion bonding is applicable to the reinforcing bars shown in Table 2. For bonding bars with different diameters, the provisions of Section 3.4 "Joints of dissimilar steels or of different diameter bars" of the Recommendations for the Design and Fabrication of Diffusion Bonded Joints in Reinforcing Bars Using Amorphous Metal Foil shall be followed.

Table 2 Reinforcing bars for amorphous metal diffusion bonding

Class Symbol	Chemical composition (mass%)					
	C	Si	Mn	P	S	C+Mn/6
SR 235	–	–	–	≦0.050	≦0.050	–
SR 295	–	–	–	≦0.050	≦0.050	–
SD 295	≦0.27	≦0.55	≦1.50	≦0.040	≦0.040	–
SD 345	≦0.27	≦0.55	≦1.60	≦0.040	≦0.040	≦0.50
SD 390	≦0.29	≦0.55	≦1.80	≦0.040	≦0.040	≦0.50

Class Symbol	Mechanical properties					
	Yield point or0.2% Proof stress N/mm²	Tensile strength N/mm²	Tensile test specimen	Elongation(%)	Bending characteristics: Bending angle	Bending characteristics: Internal radius
SR 235	235≦	300~520	No.2	20≦	180°≦	1.5×D
			No.3	24≦		
SR 295	295≦	440~600	No.2	18≦	180°≦	ϕ≦16 mm 1.5×D
			No.3	20≦		16 mm<ϕ 2.0×D
SD 295	295~390	440≦	No.2	16≦	180°≦	≦D 16 1.5×D
			No.3	18≦		D 16< 2.0×D
SD 345	345~440	490≦	No.2	18≦	180°≦	D≦D 16 1.5×D
			No.3	20≦		D 16<D≦D 41 2.0×D
						D 51 2.5×D
SD 390	390~510	560≦	No.2	16≦	180°≦	2.5×D
			No.3	18≦		

(4) Shape of reinforcing bar ends

If bending at the end of the reinforcing bars exceeds 3mm per 500mm of bar length, cutting or other corrective measures shall be carried out.

(5) Condition of reinforcing bar mating surfaces

The reinforcing bars shall be cut using high speed cutters, etc. and the mating surfaces shall be processed by disc grinders (JIS C 9611), etc. or otherwise finished so that the surface roughness R_{max} is equal to or less than 100 μ m. In addition, care shall be taken to prevent any adherence of oils, grease, rust, mud, paint or other foreign matter on the mating surfaces.

(6) Amorphous metal foils

The amorphous metal foil used for bonding shall conform to the specifications of JIS Z 3265 "Nickel Brazing Filler Metal".

The amorphous metal foil shall be used after processing to appropriate shape and dimensions depending on the reinforcing bars to be joined. In addition, there shall be no adherence of oils, grease, paint or other foreign matter on the foil.

4. Fabrication

(1) Preparations

① Discuss the details of fabrication with those charged with executing the fabrication work and decide the work plan .
② Confirm that the power source has been connected properly to the primary side of the high frequency generator, etc.
③ Confirm that earthing of the high frequency generator has been carried out properly.
④ Confirm that there is no leakage in the water piping of the cooling unit, hydraulic oil piping of the pressure applying equipment and in the shielding gas piping.
⑤ Confirm that the cables are not deformed or bent and that their insulation is not damaged.
⑥ Check the safety paths, lifts, scaffolding, etc.

(2) Processing of reinforcing bar mating surfaces

① Cut the reinforcing bars mechanically with a high speed cutter, etc. and finish the mating surfaces with a disc grinder, etc. so that the surface roughness $R_{max} \leqq 100\mu m$.
② The finishing of the mating surfaces should be performed on the day of the joining. The person performing the bonding should check the condition of the mating surfaces before commencing bonding operations.
③ Any rust, oil, grease, paint or other foreign matter adherent on the mating surfaces should be removed using a wire brush, cloth, disc grinder, etc.
④ If rust, oil, grease or other foreign matter is adherent on the surface of the metal foil, such matter should be removed carefully.

(3) Bonding operations

① Switch on the primary side power supply to start the drives of the cooling unit, control unit, hydraulic pump of the pressure applying equipment, high frequency generator, etc. and confirm that there is no leakage in the water and oil piping.
② If using shielding gas, open the valve of the gas cylinder, adjust the pressure regulator to the required pressure and confirm that there is no leakage in the gas piping.
③ Assemble the reinforcing bars in position on the pressure applying equipment and carry out the necessary adjustments to the equipment so that the gap between the mating surfaces and the axial misalignment fall within the values specified in Table 3.
④ Insert the specified amorphous metal foil between the mating surfaces of the reinforcing bars so that the entire area of the mating surfaces is covered by the amorphous metal foil

Table 3 Dimensional accuracy of reinforcing bars to be bonded

Roughness of bonding surfaces	Axial misalignment	Gap between mating surfaces
$R_{max} \leqq 100\mu m$	The smaller of the two values below: ≦Nominal diameter×0.1 ≦4mm	The smaller of the two values below: ≦Nominal diameter×0.1 ≦3mm

⑤ Operate the control unit and carry out bonding of the reinforcing bars according to the conditions shown in Table 4.
⑥ On completion of bonding, disassemble the pressure applying and other equipment from the

reinforcing bars and remove any oxides or other products formed on the bar surface.

Table 4 Standard bonding conditions for the amorphous metal diffusion bonding method

Bonding temperature	1250±50℃
Holding time	120s or longer
Applied pressure	30MPa or greater
Upset distance (Distance of contraction)	With shielding gas: 6mm or more Without shielding gas: 1/4×Diameter of reinforcing bar or greater
Shielding gas	Nitrogen gas to be used as necessary (100 l/min)

⑦ In principle, fabrication outdoors shall not be carried out in case of rain or snow fall. However, this restriction does not apply if provisions are made for suitable protection against rain and snow fall.

5. Inspection

① Carry out inspection of 100% of the joints visually and by using vernier calipers, measuring scale, etc.
② Carry out sampling inspection of the joints by ultrasonic flaw detection inspection.

6. Operator skill

Persons responsible for carrying out amorphous metal diffusion bonding operations shall belong to one of the undermentioned categories.
① A person who has acquired Class I or higher certification as a qualified manual gas pressure welding technician under the Japan Gas Pressure Welding Society's standard qualification and certification procedure for manual gas pressure welding technique, and in addition has followed the technical training program held on amorphous metal diffusion bonding.
② A person who has been certified as an amorphous metal diffusion bonding technician under the Japan Gas Pressure Welding Society's standard qualification and certification procedure for high frequency pressure welding with amorphous metal foil.