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Author(s)	Murakami, Kazumi; Maeda, Naoki; Kanematsu, Hideyuki et al.
Citation	Transactions of JWRI. 2007, 36(1), p. 13-19
Version Type	VoR
URL	https://doi.org/10.18910/11831
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Effect of Concrete Rebar Joint Arrangement on Weldability of Hot-dip Galvanized Rebar by Shielded Metal Arc Welding†

MURAKAMI Kazumi*, MAEDA Naoki, KANEMATSU Hideyuki*** and NAKATA Kazuhiro******

Abstract

The applicability shielded metal arc welding to make a joint in hot-dip galvanizing steel rebars used for concrete reinforcement has been discussed. The concrete rebar has many projection points to assure its adhesion with concrete. The influence of these projections at the flare groove joint arrangement on the effectiveness of shielded metal arc welding has been investigated. As a result, the optimum arrangement of projection points in the flare groove joint, which leads to reduced cavity formation and increased joint shear strength, has been clarified.

KEY WORDS: (Hot-dip galvanizig) (Steel bars for concrete reinforcement) (Shielded metal arc welding) (Joint arrangement) (Cavity)

1. Introduction

Concrete has played an important role in infrastructure development so far. However, recently, the collapse of concrete structures has become a frequent topic. There seem to be several causes for this, and rebar corrosion in concrete is one of the major ones[1)]. For the corrosion protection of steel bars used to reinforce concrete, rebars painted with epoxy resin have been mainly used so far. However, it is feared that a big problem may develop if a defect is caused during transportation and construction. On the other hand, although it has been thought that galvanization is melted in concrete, which is a highly alkaline environment, leading to a lack of corrosion resistance, it has been reported recently that compounds generated by the reaction between zinc and cement components greatly improve corrosion resistance or adhesiveness to concrete[2-4)]. However, since zinc's melting and boiling points are 420°C and 906°C, respectively, it is feared that it may be melted or evaporated to a gas, leading to defects such as blow holes or pits when welding is performed. For the welding of hot-dip galvanized steel plates, it is known that the zinc vapor generated from the galvanized layer causes blow holes, pits, and sputtering[5,6)]. Hence, a welding construction method to prevent pits or blow holes from being generated has been proposed whereby the galvanized layer is removed before starting welding construction[6)]. In addition, it has been reported that zinc is removed using the cleaning effect of arcs[7)], and it has also been reported that spattering and blow holes are reduced[8)] by applying pulse MAG welding. Furthermore, as a method related to the press forming of members, it has been proposed to form protrusions on the flange part of an overlapping fillet joint simultaneously with press forming to provide a root gap on the overlapped portion so that the zinc vapor arising from the leading-edge of the weld pool can disperse easily[9)]. However, there is no report of welding a bar steel for reinforced concrete (by-form bar steel) by the shielded metal arc welding method. Differently from normal galvanized steel plates, since hot-dip galvanized rebars have many protrusions on the surface to ensure their adhesiveness to concrete, we cannot ignore the influence of these protrusions. Therefore, in this study, we analyzed the flared joints of hot-dip galvanized rebars processed by the shielded metal arc welding method, considering the influence of rebar joint arrangements, welding bars, welding currents, and rod operating methods on porosity occurrence, penetration ability, and joint strength, and selected the optimal welding condition.

2. Materials and Experimental Methods

2.1 Hot-dip Galvanized Rebars

As the samples, we cut steel bars for reinforced concrete (JIS G 3112 by-form bar steel SD295A D19 and D22, hereinafter called normal rebars) into pieces 1m long,

† Received on June 22, 2007
* Mie Prefectural Science and Technology Promotion Center
** Tsu High Technique School
*** Dept.MS&E,Suzuka National College of Technology
**** Professor
Transactions of JWRI is published by Joining and Welding Research Institute, Osaka University, Ibaraki Osaka 567-0047, Japan

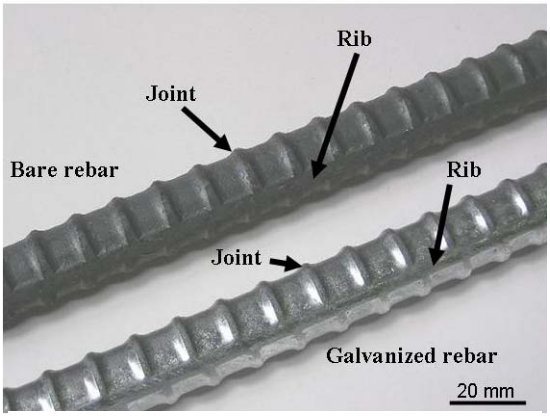


Fig. 1 Appearance of concrete rebar flare joint.

respectively, applied hot-dip galvanization to them, and used them as hot-dip galvanized rebars. The thickness of hot-dip galvanization was 60 to 80 μm, and the quantity of attached galvanization was 550 g/m^2. **Figure 1** shows the appearance. We call the protrusions perpendicular to the axial direction "joints," and those parallel to the axial direction "ribs". The nominal diameters of normal rebars D22 and D19, which were used for this study, were 22.20 mm and 19.10 mm, respectively. In addition, the average intervals of the "joints" were 13.0 mm for D19 and 15.0 mm for D22. The heights of the "joints" and "ribs" were 1.5 mm for D19 and 1.7 mm for D22. The angles of the "joints" and "ribs" to the axial lines were around 45 degrees, respectively.

2.2 Welding Methods and Welding Bars

Welding was conducted by the shielded metal arc welding method. We used two types of welding rods: D4301 of the ilmenite type and D4340* of the special type. Both of these bars are commercially available. Both had a diameter of 3.2 mm. **Table 1** shows the chemical compositions of the welding rods and fluxes we used. Although there was no significant difference between the chemical compositions of the two welding rods, for the chemical compositions of the flux, it was found that the welding rod for hot-dip galvanized steel plates contains more iron.

Table 1 Chemical compositions of welding rod and flux.

Rod	Chemical compositions (mass%)				
	C	Si	Mn	P	S
D4301	0.100	0.100	0.430	0.017	0.008
D4340	0.068	0.100	0.480	0.019	0.008

Flux	Chemical compositions (mass%)									
	C	Fe	Si	Mn	Ca	Ti	K	Al	Mg	Zr
D4301	83.1	1.43	6.52	1.73	3.56	2.15	0.74	0.55	0.13	0.01
D4340	81.0	4.28	5.69	0.99	3.13	2.33	1.04	0.88	0.66	0.02

* Commercially sold as a welding rod for hot-dip galvanized steel plates

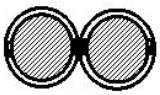
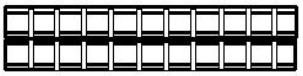
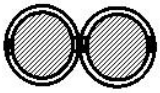
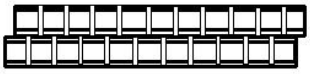
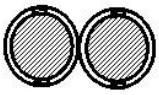
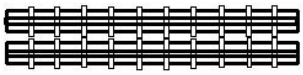
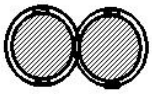
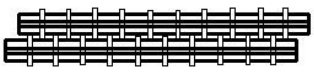
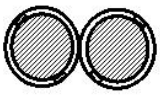
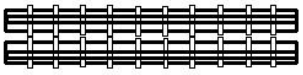
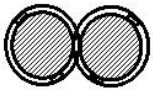
2.3 Welding Current and Rod Operating Methods

Welding was conducted using a direct current with positive polarity with two welding current, 110A and 130A. Two types of rod operating methods, straight and weaving methods, were applied. Although there are many cases of construction by the two-pass method using a welding rod with a diameter of 3.2 mm (straight rod operating method) and the three-pass method using a welding rod with a diameter of 4.0 mm (weaving rod operating method), the four-pass method was adopted in all welding conditions in this study. The welding speed was 30 cm/min on the first pass, and 25 cm/min on and after the second pass.

2.4 Rebar Arrangement

Normal rebars have horizontal and vertical protrusions to reinforce their adhesion to concrete. We considered the influence of the direction and position of these "rib" and "joint" protrusions on the characteristics of welding. In this study, the positional relations of the rebars to be welded at the flared joints were classified into six patterns, as shown in **Table 2**. Among this group, since there was no significant difference between rebar joint arrangement types 3/4 and types 5/6 in the gap between the mutual rebars regarding the groove weld area and root gap, rebar joint arrangement types 1, 2, 5, and 6 were considered.

Table 2 Arrangement of concrete rebar flare joint.

Type	Concrete rebar arrangement	
	Cross section	Appearance
1		
2		
3		
4		
5		
6		

3. Experimental Results

3.1 Appearance of Welding Beads and Welding Workability

3.1.1 Welding Rods

Figure 2 shows the appearance of the welding beads on the samples of the hot-dip galvanized rebars with different rod diameters (D22 and D19) which were processed by the shielded metal arc welding method using two types of welding rods, respectively. The welding current was 130A, the rod operating method was the weaving type, and the rebar joint arrangement type was 6. For the sample which was welded using welding rod D4301 (Fig. 2(a) and (b)), the ripple pattern appeared on the surface of the welding beads prominently, and significant unevenness was observed. In addition, a large amount of spatter was generated. The shape of the ripple pattern seems to be caused by the good fluidity of the slag, which is a characteristic of the welding rod. On the other hand, the spatter seem to be generated because the shapes of the rebars are different to each other and a sufficient root gap is not provided. On the appearance of the beads of the sample which was welded using welding rod D4340 (Fig. 2(c) and (d)), little spatter was generated, so that stable, glossy, and smooth welding beads were obtained. In addition, there was a tendency that with D4340, face reinforcement was higher than that with D4301. This means that the flux has been improved as an agent for hot-dip galvanized steel plates. However, the generation of spatter has not been suppressed sufficiently. The cause of this is as mentioned above. It can be noted from these results that better welding workability can be obtained when hot-dip galvanized rebars are welded not employing a generally-used ilmenite welding rod, but using a welding rod for hot-dip galvanized steel plates, which are not employed for rebars.

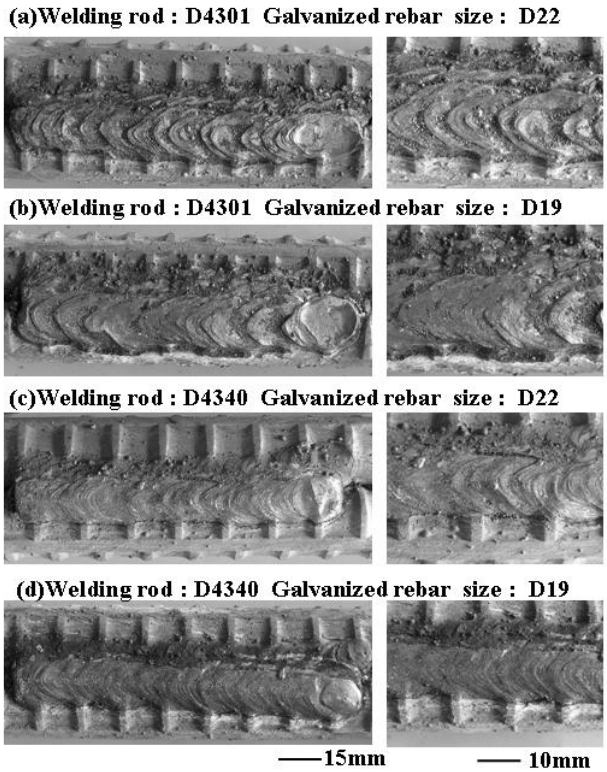


Fig. 2 Appearances of flare joint of concrete rebar.

3.1.2 Welding current and Rod Operating Methods

Figure 3 shows the appearance and photographs of the cross-section macro structures of the welding samples to which different welding current and rod operating methods were applied. The welding rod was D4340, the rebar was the hot-dip galvanized rebar, the diameter of the rebar was D22, and the rebar arrangement type was 6. First, when comparing the samples welded by the same weaving rod operating method but using different welding currents (Fig. 3(a) and (b)), although the generation of some spatter was recognized on each of the samples, smooth-looking welding beads were obtained from both of them. However, when 110A (Fig. 3(b)) was applied, a spot seeming to be a slag inclusion was observed in the lower left area of the center of beads, as shown in the photograph of the appearance (circled area on the photograph). In addition, it was found from the results of each observation of the macro structures that the status of

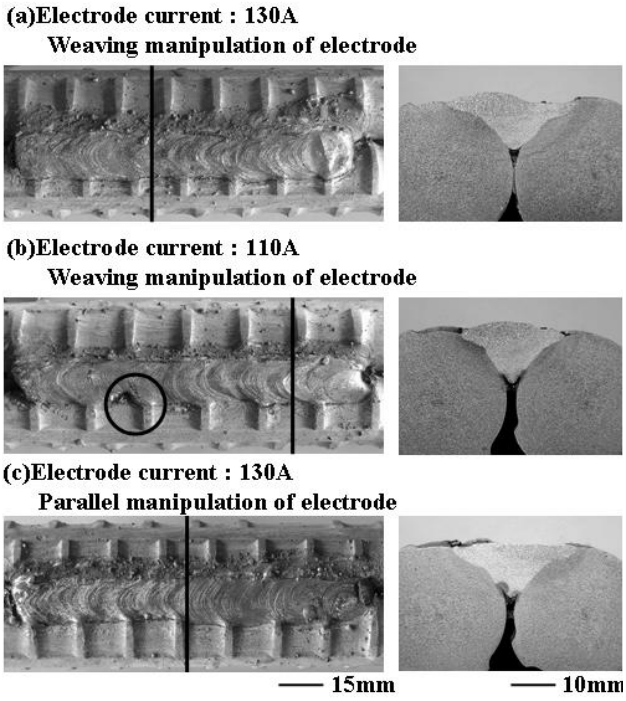


Fig. 3 Appearance and cross-sectional macrostructures of concrete rebar flare joint.

welding around the end stop was better when 130A was used. From these results, it was found that 130A was appropriate for the rebar with a diameter of D22 in the scope of this study. Next, when comparing the welding samples which were welded using the same welding current but different types of rod operating methods (Fig. 3(a) and (c)), it was found that the straight rod operating method (Fig. 3(c)) is inferior to the weaving rod operating method (Fig. 3(a)) in terms of the apparent smoothness of beads. Moreover, from cross-sectional observation it was noted that penetration was worse around the root when the straight rod operating method was applied. This seems to be because the welding speed of the straight rod operating method is faster, so that the quantity of heat input into the rebar welding portion is not sufficient. Although the straight rod operating method is also used for normal rebars, from the viewpoint of work efficiency in actual cases of construction, it was found that the weaving rod operating method is better for hot-dip galvanized rebars from the viewpoint of the penetration status.

3.2 Penetration Depths and Cross-section Shapes

3.2.1 Influence of Welding Rods and Rod Operating Methods

Figure 4 shows the penetration depth of each sample in various conditions. Each of the sample names indicates the rebar diameter - welding current - rod operating method. For example, 22-130-W indicates a sample with a D22 rebar diameter processed using a welding current of 130A and the weaving rod operating method. The "S" of the rod operation method indicates the straight rod operating method. The penetration depth was measured by defining the tangent of the circumferences of both the welded rebars as a starting point, so that the influence of excess weld metal could be excluded. In addition, the penetration depth was measured at a total of five positions (three including "joints" and two excluding them), and their average was adopted as the penetration depth of the sample. The penetration depth is one of the factors influencing the bonding strength of joints, and it is better to make this depth as large as possible. First, for the difference between the welding rods (the dotted and hatched columns in the figure), welding rod D4301 provides deep penetration irrespective of the welding current and rod operating method. One of the causes of this characteristic is the high fluidity of the welding metal. However, taking the appearance of the beads and the occurrence of sputters into consideration, this method is not necessarily satisfactory. Next, when comparing the sample of the hot-dip galvanized rebar welded using welding rod D4340 (dotted columns in the figure) to the sample of the normal rebar welded using welding rod D4301 (open columns in the figure), penetration depths were almost the same irrespective of the welding current and rod operating method. Based on these results, for hot-dip galvanized rebars, a welding strength equivalent to that of the flared welding of normal rebars can be achieved using welding rod D4340, an welding current of 130A, and the weaving rod operating method.

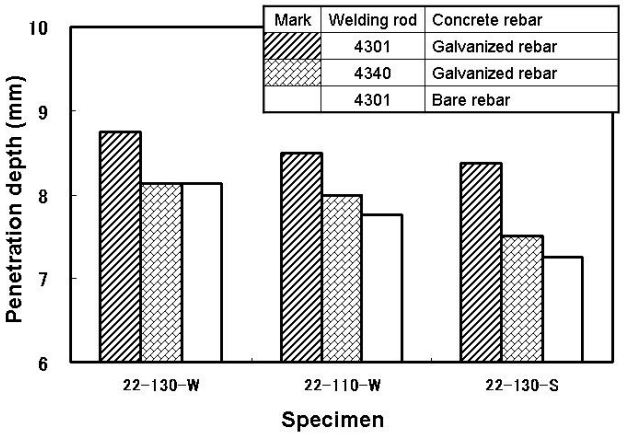


Fig. 4 Influence of different parameters on penetration depths of flare joints.

3.2.2 Influence of Rebar Arrangement

Figure 5 shows typical rebar joint arrangements and variations of the groove weld area and root gap depending on the joint positions. This figure shows that the groove

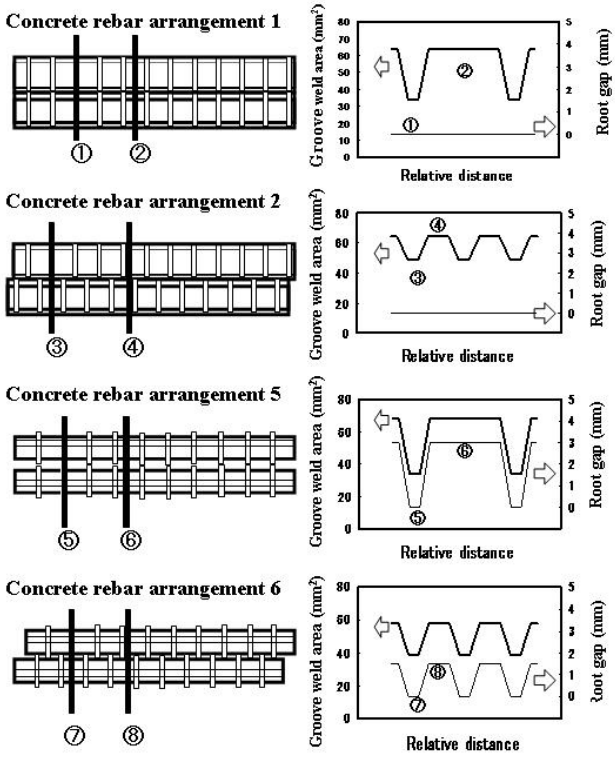


Fig. 5 Schematic illustration of typical concrete rebar arrangements and variations in groove weld area and root gap at different flare joint positions.

weld area (the area of the portion enclosed within the broken lines of the mutual rebars and the rebar circumferences) and groove interval of the portion to be welded vary depending on the positional relation of the "joints" and "ribs." Differently from the welding of steel plates, the groove area to be welded is supposed to vary due to the existence of "joints" and "ribs" even in a single pass, so that this might prevent rebars from being welded steadily. In particular, in rebar joint arrangements 1 and 5, the groove weld area varies much more because the portion at which the "joints" of both rebars are located and the portion at which no "joints" occur come repeatedly. Although the variation is smaller in rebar joint arrangements 2 and 6, this variation is repeated at short, constant intervals. In addition, welding is performed across the "joints" at positions ①,③,⑤, and ⑦, and this influences the moving of the welding rod. On the other hand, there is no root gap in rebar joint arrangements 1 and 2 because the "ribs" contact each other, but variation is repeated at constant intervals in rebar joint arrangements 5 and 6 depending on the positional relation of the "joints", although there is no influence of the "ribs." Based on this figure, we are able to classify the combinations of the groove weld area and root gap into eight patterns, numbered ① to ⑧ in the figure.

Figure 6 shows the results of the welded cross-section's macro structures of the hot-dip galvanized rebars, corresponding to patterns ① to ⑧ in Fig. 5. The welding rod was D4340, the welding current was 130A, and the rod operating method was the weaving method. In shielded metal arc welding, the root gap is an important factor influencing the quality of welding. Furthermore, when zinc is vaporized in the welding of hot-dip galvanized rebars, it is important to know how many portions are grooved with open root gap. First, in the cross-sectional photographs ① to ④ in rebar joint arrangements 1 and 2, there is no gap between the mutual rebars because the "ribs" of the rebars contact each other. Hence, it was observed that a cavity was formed due to trapping the zinc vapor generated from the galvanization. This trend was marked in cases ① and ③. This is mainly because there is no gap between the mutual rebars, and the "joints" of the mutual rebars are located at the same positions, so that the groove weld area is also small. In addition, another cause of zinc vaporization seems to occur whereby the arc becomes unstable due to passing through the "joints". On the other hand, in cases ② and ④, it seems that little zinc vapor remained in the beads because the groove weld area is large, even though a cavity created by zinc vaporization was observed. Next, in rebar joint arrangements 5 and 6, although a certain

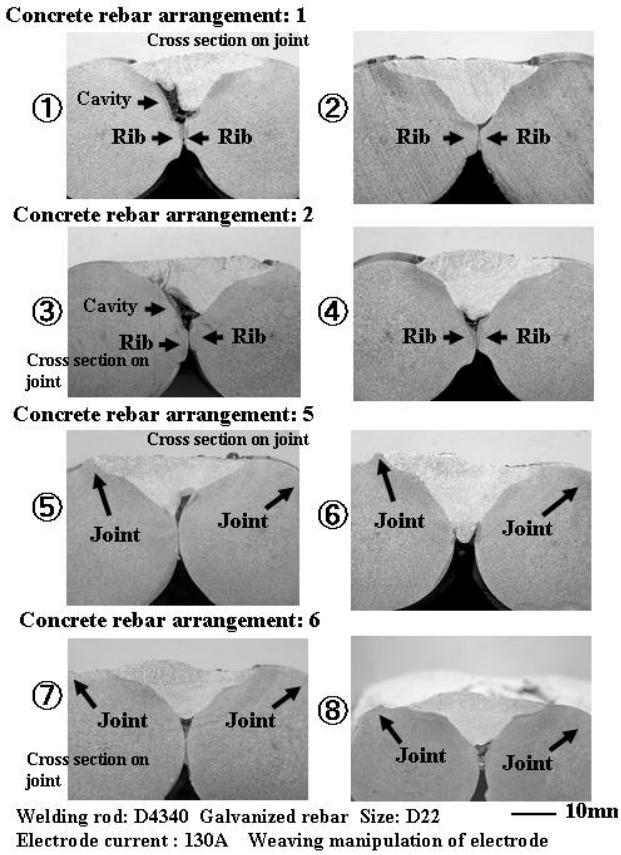


Fig. 6 Macrostructures of cross-sections of flare joints with different rebar arrangements.

size of gap can be maintained between the mutual rebars because their "ribs" do not contact each other, there is no gap between the mutual rebars depending on the positions of the "joints." In cases ⑤ and ⑦, in which there is no such gap, although a cavity created by zinc vapor inclusion, as shown in the description of rebar joint arrangements 1 and 2, occurred, this cavity is small compared to the bead's cross-section. This means that the cavity becomes smaller when the "joints" are located at the same positions in rebar joint arrangements 5 and 6, because the degree of adhesion is lower than that when the "ribs" are in contact with each other, like in rebar joint arrangements 1 and 2, so that zinc vapor can be ventilated. On the other hand, in cases (cases ⑥ and ⑧) in which the "joints" are not relevant to the gap between the mutual rebars in rebar joint arrangements 5 and 6, good welding was achieved because zinc vapor is ventilated easily due to the gap between the mutual rebars on the lower side. Few cavities were formed when the gap between the mutual rebars was small due to the positional relation of the "joints" (⑧). From the results of observing the macro structures of the cross-sections among different types of rebar joint arrangements, it was found that the positional relation of the mutual rebars to be welded (rebar joint

arrangements in this study) greatly influences the welding results when the shielded metal arc welding of hot-dip galvanized rebars is applied, compared with the differences of welding rods, welding current, and rod operating methods.

3.3 Zinc Vaporization and Cavity Formation

Figure 7 shows the results of SEM observation and EDX analysis at a cavity on the cross-section of rebar joint arrangement 1 (①). Since zinc was significantly enriched in the cavity, we guessed that zinc vapor generated by hot-dip galvanization was trapped in the gap between the welded metal and rebar, and formed the cavity. The value calculated by dividing the area of this cavity into which zinc was included by the area of the bead below the tangent of the mutual rebars is called the cavity area ratio.

3.4 Influence of Groove Weld Area and Root Gap on Cavity Area Ratio

Figure 8 shows the relation among the cavity area ratio, groove weld area, and root gap on each cross-section. The suffixes in the figure show the values of the cavity area ratio. In this figure, when comparing the welded portions with a 60 to 70 mm^2 groove weld area, which is very similar, to each other, the cavity area ratio clearly decreased as the root gap increased. In addition, even when there was no root gap (0), the cavity area ratio clearly decreased as the groove weld area increased. In other words, both the root gap and groove weld area are related to the cavity area ratio, and to perform good welding with a small cavity area ratio, welding must be performed using a rebar joint arrangement in which the groove weld area and root gap are large. In short, it is found that rebar joint arrangements 5 and 6 have smaller

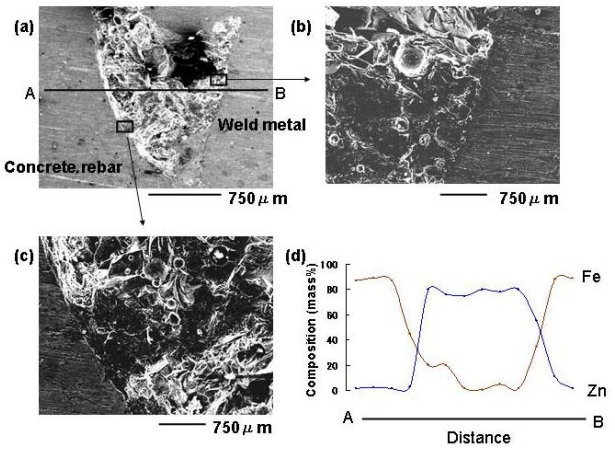


Fig. 7 SEM observation of a cavity(a, b, and c) and EDX line analysis of Zn and Fe (d) along the A-B line.

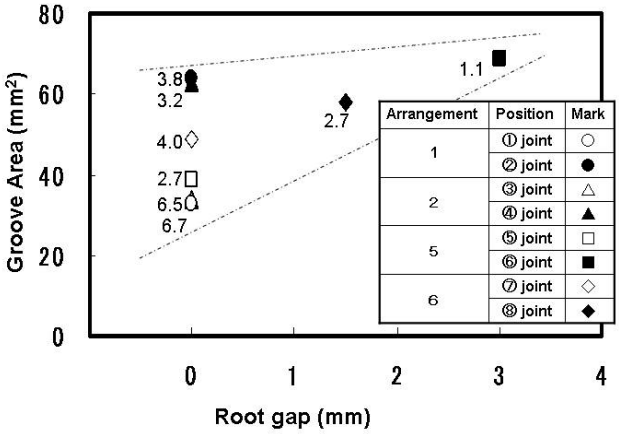


Fig. 8 Combined effect of root gap and groove area on the cavity area of a flare joint of galvanized rebar D22; D4340,130A,Weaving.

cavity area ratios than rebar joint arrangements 1 and 2, and this facilitates satisfactory welding.

3.5 Joint Tensile Shear Strength and Rebar Arrangement

Figure 9 shows the relation between joint tensile shear strength and rebar joint arrangement. The length of the bead was defined as five times longer than the nominal diameter of the rebar in all cases**. The joint tensile shear strength of rebar joint arrangement 5 showed the highest value. After that, although the joint tensile shear strength decreased in the order of rebar joint arrangement 1, 6, and then 2, the differences were small. All fracture positions in each sample were near to the boundaries of the rebars in the welding beads. This seems to have been caused because a cavity including zinc vapor was created at the boundary between the galvanized rebar and welding beads, and the fractures were generated due to cavity presence. Hence, the tensile shear strength of rebar joint arrangement 5, which showed a small cavity area ratio,

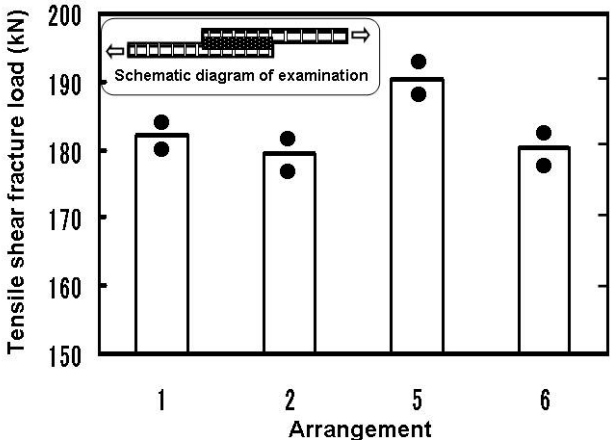


Fig. 9 Relationship between tensile shear fracture strength and flare joint arrangement.

** The required length for settling on floors, slabs, and so on in actual construction is 10d[10]. However, rebar break-off was observed on all the samples whose bead lengths were defined as 10d. However, d was the diameter of the rebar.

seemed to be high.

From these results, the following was concluded: No particular attention had been paid to rebar joint arrangement for the flared joints processed by shielded metal arc welding of normal rebars; however, it is desirable to adopt rebar joint arrangement 5, in which the "ribs" do not contact each other, when the shielded metal arc welding of hot-dip galvanized rebars is applied from the viewpoint of the ease of ventilating zinc vapor.

4. Conclusion

In this study, we aimed at applying hot-dip galvanization to bar steels for reinforced concrete, and considered the application of shielded metal arc welding at the flared joints of hot-dip galvanized rebars. The results were as follows:

(1) For the shielded metal arc welding of hot-dip galvanized rebars, welding can be improved using a welding rod for hot-dip galvanized steel plates rather than a welding rod of the ilmenite type.

(2) For the shielded metal arc welding of hot-dip galvanized rebars, from the viewpoint of preventing cavity defects, welding can be improved using the weaving rod operating method as opposed to the straight rod operating method.

(3) The zinc vapor generated from hot-dip galvanized rebars is trapped in the gaps between the welded metal and rebars, forming cavities. The cavity area ratio decreases as the root gap and groove weld area increases.

(4) The cavity area ratio and tensile shear strength vary depending on the rebar joint arrangement, and effective welded joints can be obtained from some rebar joint arrangements. In other words, it was concluded that rebar joint arrangements without "ribs" contacting each other (arrangement patterns 5 and 6 in Table 2) are desirable from the viewpoint of the ease of zinc vapor ventilation through root gaps.

The hot-dip galvanization applied in this study provided sufficient adhesiveness to ensure corrosion resistance in concrete.

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