Gas Pressure Welding Method for Steel Reinforcing Bars

A hot shearing method for removing flash is proposed as a way to inspect the integrity of gas pressure welds

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ABSTRACT. In Japan, the majority of steel bars are welded by gas pressure welding. This is because gas pressure welding is superior to other joining methods in its workability.

In the Hanshin-Awaji earthquake of January 17, 1995, many gas pressure welds in reinforced concrete were broken at the weld interface. Since then, a reliable quality inspection method has been demanded.

A method of flash removal by hot shearing, which makes it possible to easily inspect the weld immediately after welding, has been recently developed. This method is effective in evaluating gas pressure welds in real time, and it possesses high workability and high reliability.

The reliability of inspection methods, such as penetrant testing, ultrasonic testing and flash removal by hot shearing, was verified by tensile and bending tests of welded joints. Then the relation between the inspection results and the destructive testing results was investigated. As a result, it was clear that flash removal by the hot shearing method displayed the highest reliability. Thus, flash removal by hot shearing is superior to penetrant testing and ultrasonic testing as a quality inspection method for gas pressure welds.

Introduction

In Japan, three types of joints, namely a welded joint, a lap joint and a mechanical joint, are applied for joining steel bars. The lap joint is mainly applied for joining steel bars with diameters less than 16 mm. On the other hand, the welded joint and the mechanical joint are applied for joining steel bars with diameters more than than 16 mm. Among these joints, the welded joint accounts for approximately 90% (Ref. 1), and the majority is executed by gas pressure welding. It is probably because gas pressure welding is superior in workability to other joining methods for this application.

In the Hanshin-Awaji earthquake (magnitude M = 7.2), many gas pressure welds in reinforced concrete were broken at the weld interface (Ref. 2). Since then, a reliable quality inspection method has been demanded.

The ultrasonic inspection method has been widely used as a quality inspection method for gas pressure welds on steel bars in Japan (Ref. 3). It is known that this method has a few problems: 1) outer side of the interface could not be inspected, 2) interpretation varies depending on the inspector and 3) the welded portion should be cooled, resulting in a time interval before inspection can occur. As a result of these circumstances, a method of flash removal by hot shearing was developed that allows easy weld inspection immediately after welding. This inspection method is effective for evaluating gas pressure welding in real time.

This report describes the features and fundamental principles of gas pressure welding, and then explains the validity of flash removal by hot shearing as an inspection method for weld quality.

KEY WORDS

Gas Pressure Welding
Quality Estimation
Steel Reinforcement Bar
Hot Shearing
Weld Defect
Appearance Testing
Plastic Deformation
FEM

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Features and Fundamental Principles of Gas Pressure Welding

Gas pressure welding is a solid phase method. This method is executed as follows: 1) butting the end surface of materials against each other, 2) heating the faying face by oxyacetylene flame with pressure applied and 3) stopping the heating and pressure when upsetting length reaches the predetermined value. Figure 1 illustrates the gas pressure welding procedure.

Application of Gas Pressure Welding

The gas pressure welding method was similarly developed in the United States (Ref. 5) and Japan (Ref. 6) in the 1930s. Since then, it has found wide application and is commonly used to weld steel reinforcing bars, rails and pipes. Further investigations concerning this method were conducted in Germany, Russia (formerly USSR) and Japan. However, it has been applied rarely anywhere other than in Japan and Russia since the 1960s.

In Japan, various studies on procedure, apparatus, applicable materials and pressure welding phenomena have been performed since the gas pressure welding method was developed. Presently, approximately a quarter of continuous-welded rails are produced by the gas pressure welding method (Ref. 7) and a large amount of steel reinforcing bars are joined by this method in the civil engineering and construction fields (Ref. 1).

Gas Pressure Welding Phenomena

Gas pressure welding is not fusion welding. It is a solid phase type of welding that accomplishes joining without a significant melt of the base metal. The atom reconfiguration at the weld interface is accomplished by heating the faying surface above the recrystalization temperature and the joining results from plastic deformation caused by compression (Ref. 4).

In gas pressure welding of steel bars, however, the end surfaces of the bars to be welded are always oxidized during the welding in spite of using a reducing flame. So if the joining procedure is poor, oxide inclusions will remain at the weld interface. As a result, those inclusions will cause weld defects.

When the oxide inclusions exist at the weld interface, the fracture surface from bending tests looks smooth and gray (herein referred to as "flat fracture") as shown in Fig. 2. There is a fine dimple pattern, and spherical oxide inclusions consisting mainly of MnO and SiO_2 are observed in each dimple. The existence of oxide inclusions at the weld interface causes a drop in strength. Moreover, flat fracture is generally formed on the outer side as shown in Fig. 2A.

Influential Factors on Gas Pressure Weld Quality

It is well known that the quality of solid phase welding is affected by heating temperature, upset length, surface condition and atmosphere (Ref. 8). However, less work has been done on ways to suppress flat fracture. So, in this study, various tests were done regarding the formation of flat fracture. Results obtained are detailed below.

Figure 3 shows that a critical line, at which the flat fracture disappears in the weld interface, is determined by a maximum heating temperature T and an area expansion factor K of the weld interface. This figure is based on experiments. An area expansion factor is an expanded ratio of the weld interface. For example, $K = 2$ means that the area of weld interface spreads to twice the initial value. The formation of flat fracture is suppressed by increasing the maximum heating temperature T and the area expansion factor K as shown in Fig. 3. This

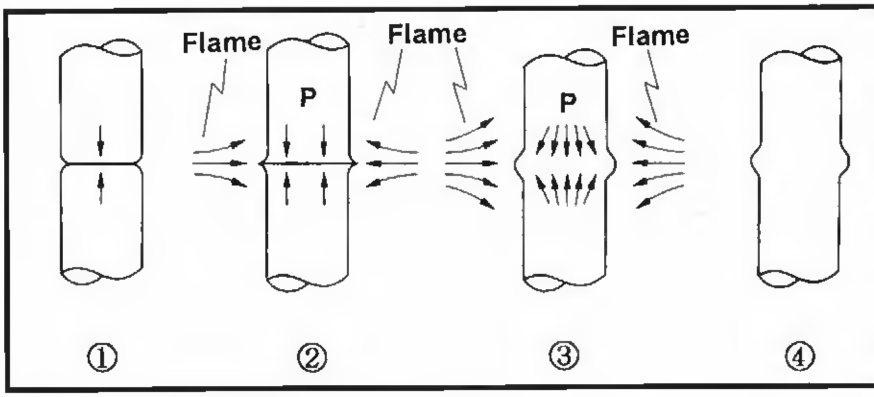

Fig. 1 — Illustration of the gas pressure welding procedure.

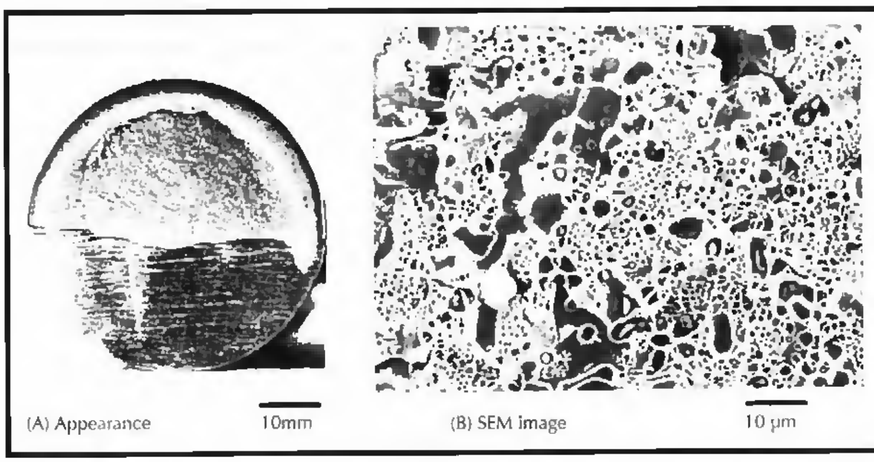

Fig. 2 — Flat fracture observed on fracture surface from bending test. A — Appearance (10 mm); B — SEM image (10μm).

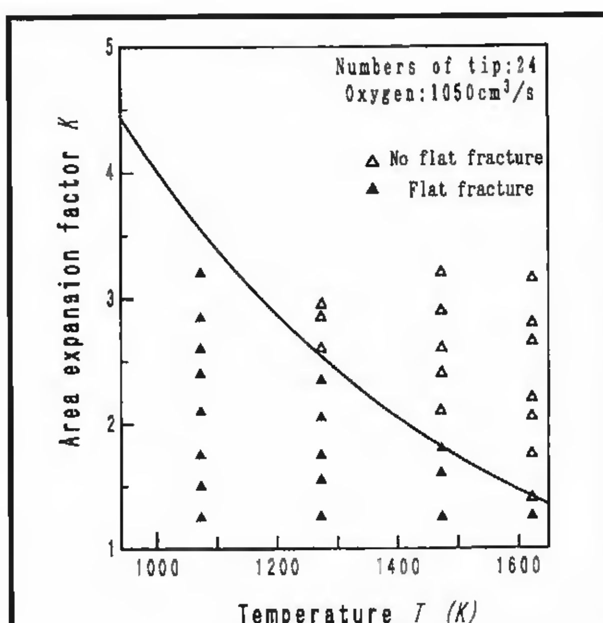

Fig. 3 — Effect of heating temperature and the area expansion factor on formation of flat fracture.

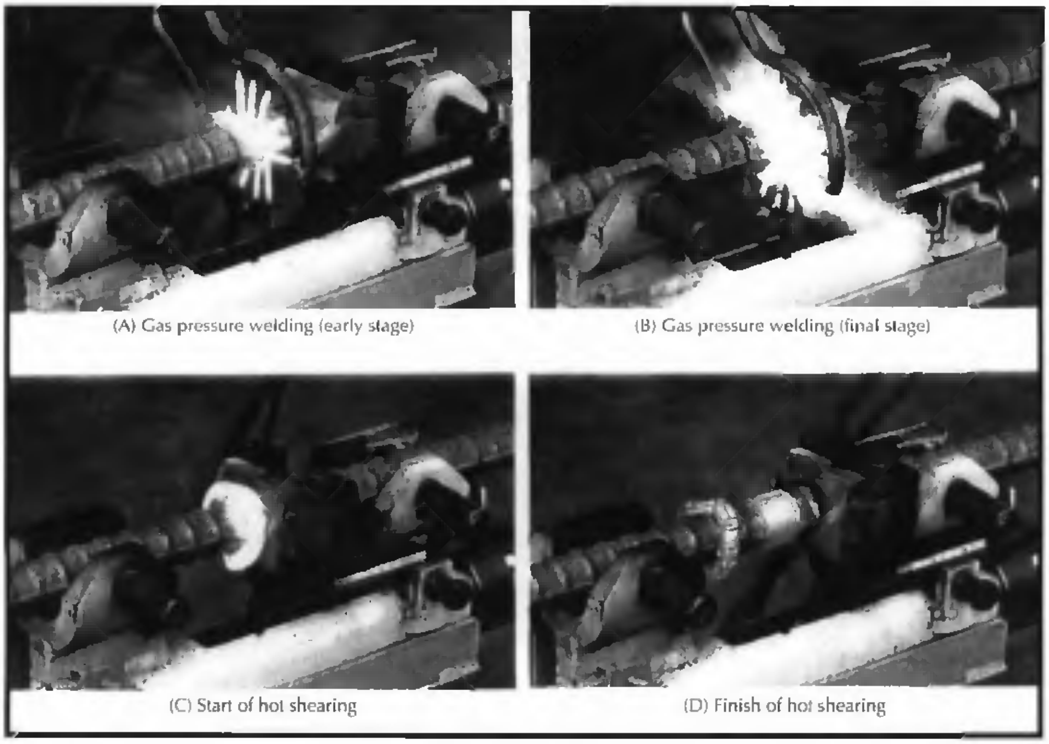

Fig. 4 — Gas pressure welding and hot shearing procedures.

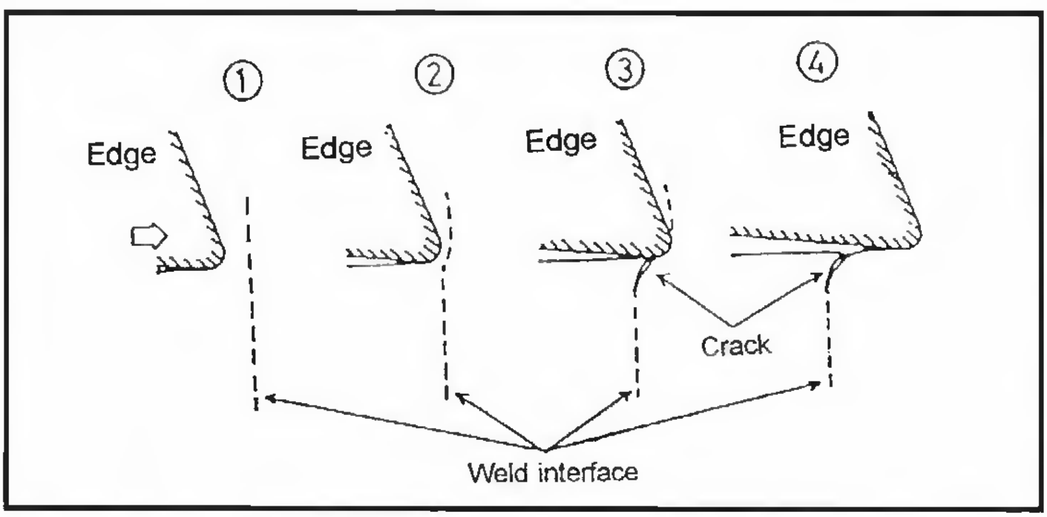

Fig. 5 — Schematic illustration of crack formation process from hot shearing. 1) The influence of the shearing edge does not extend to the interface of the gas pressure weld. 2) The shearing edge goes forward, and the section near the interface of the gas pressure weld moves into the plastic deformation area. If metallic bonding strength is very low, a crack occurs at this step. 3) The edge passes the interface of the gas pressure weld. When metallic bonding strength is low, a crack always occurs at this step. 4) The crack, which occurred at step 3, is on the surface; therefore, it is possible to reliably detect this flaw by appearance or by magnetic particle testing.

is attributed to the maximum heating temperature *T* promoting the reduction of oxides by carbon contained in the matrix and to the area expansion factor serving to disperse the inclusions remaining at the weld interface. In fact, welding conditions are decided by using these experimental results.

Quality Evaluation of Gas Pressure Weld by Hot Shearing Method

Evaluation of weld quality is extremely important in construction. Ultrasonic testing, according to the JIS Z 3062 (*Methods of Ultrasonic Examination for Gas Pressure Welds of Reinforcing Deformed Bars*), has been widely used in Japan for quality evaluation of gas pressure welds. However, this ultrasonic testing is not always reliable. Moreover, high productivity is demanded in construction, and steel bar joints are buried into concrete immediately after welding, making it difficult to inspect the joints later. Therefore, the quality inspection method for gas pressure welds must have high reliability as well as high workability. As a result of these circumstances, flash removal by a hot shearing method was developed. The inspection mechanism and validity of flash removal by hot shearing are discussed below.

Quality Evaluation Mechanism

Flash removal by hot shearing is a method for removing flash by a trimming bite immediately after welding. It is possible to inspect all of the welds after this removal because welders can directly confirm the appearance of the defect on the surface when it occurs at the weld, because flat fracture is usually formed near the surface as mentioned above. Figure 4 shows the procedures of the gas pressure welding process (a and b) and the trimming process (c and d). It is easy to remove the flash immediately after welding because the trimming device is built into the gas pressure welding apparatus.

When flash removal is performed within a few seconds after the flame has been extinguished, a plastic deformation is caused in the area under the shearing edge. Consequently, if the metallic bonding strength is low, a crack occurs at the weld interface because the joint is not able to endure the stress caused by plastic deformation. This principle is illustrated in Fig. 5.

Further, the phenomena are confirmed by means of finite element analysis. Figure 6 shows the axial stress distributions in hot shearing after pressure

Table 1 — Chemical Compositions and Mechanical Properties of Specimens

	Chemical Compositions (mass %)									Mechanical Properties		
Material	C	Si	Mn	P	S	Cr	Cu	Sn	C + Mn/6	YP (N/mm^2)	TS (N/mm^2)	El (%)
SD345	0.28	0.27	1.08	0.014	0.018	0.16	0.26	0.016	0.46	402	596	25
Spec.	≦0.27	≦0.55	≦1.60	≦0.040	≦0.040	—	—	—	≦0.50	345 to 440	490≦	20≦

welding under conditions of a heating temperature of 1273 K and upsetting length at 30 mm. A tensile stress arises in the region of the front edge. This region extends into the prescrapping area, and the value of the tensile stress increases up to 40 MPa when the edge passes the interface of the gas pressure weld — Fig. 5. Consequently, if joint strength is low, a crack is caused by this tensile stress. In other words, a gas pressure weld is considered good when a crack is not observed on the surface subjected to hot shearing.

Defect Generated by Hot Shearing Method

Figure 7 shows an example of good weld appearance after hot shearing. A flaw is not observed on the weld surface. On the other hand, Figs. 8–10 show examples of welds that are judged to be inferior. Figure 8 shows a crack. Figure 9 shows a surface on which a line flaw is formed along the weld interface. Figure 10 shows a surface severely roughened by overheating. If these kinds of conditions are observed, the weld should be judged to be inferior.

Figure 11 shows plastic deformations from hot shearing revealed by FEM in both sufficient and insufficient gas pressure welds. Macrostructures of the hot shearing stage of gas pressure welds on steel bars are shown in Fig. 12. The shape in Fig. 12 closely corresponds to that in Fig. 11. This shape can come from stress distributions as shown in Fig. 6. Accordingly, an evaluation of gas pressure weld quality can be accomplished by flash removal with the hot shearing method.

Reliability of Flash Removal by Hot Shearing Method

Quality Inspection Method

The reliability of flash removal by hot shearing as a quality inspection method is investigated by comparing it with other inspection methods. Penetrant testing and ultrasonic testing were used as comparisons. The reliability of each method of inspection, which was done after flash removal, was determined from the results of tensile and bend tests of welded joints. In tensile tests, tested joints that fractured in the base metal were judged to be acceptable; those that fractured at the weld interface were judged to be unacceptable. In bend tests, on the other hand, the tested joints that were bent beyond 90 deg without cracking were judged to be acceptable, and those that broke or cracked at less than a 90-deg bend were judged to be unacceptable. Steel bars used in tests are those for concrete reinforcement with SD345 (Ref. 9) of nominal diameter 31.8 mm. Table 1 shows the chemical compositions and mechanical properties of the steel bars used.

Table 2 — Comparison of Tensile Test Results and Inspection Results

	Hot Shearing Method		Ultrasonic Method		Penetrant Method	
	Acceptable	Unacceptable	Acceptable	Unacceptable	Acceptable	Unacceptable
Qualify	61	1	59	3	62	0
Disqualify	10	63	19	54	23	50
Misjudgment ratio	(10 + 1)/135 = 8.1%		(19 + 3)/135 = 16.3%		(23 + 0)/135 = 17.0%	

Table 3 — Comparison of Bending Test Results and Inspection Results

	Hot Shearing Method		Ultrasonic Method		Penetrant Method	
	Acceptable	Unacceptable	Acceptable	Unacceptable	Acceptable	Unacceptable
Qualify	42	2	43	2	45	0
Disqualify	7	49	13	42	12	43
Misjudgment ratio	(7 + 2)/100 = 9.0%		(13 + 2)/100 = 15.0%		(12 + 0)/100 = 12.0%	

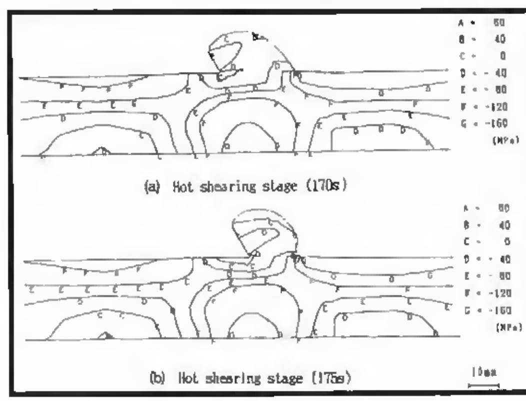

Fig. 6 — Axial stress distributions by hot shearing.

Fig. 7 — Appearance of a good weld.

Fig. 8 — Example of a crack observed on the surface.

Fig. 9 — Examples of line flaw observed on the surface.

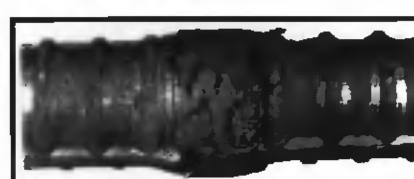

Fig. 10 — Examples of surface roughened by overheating.

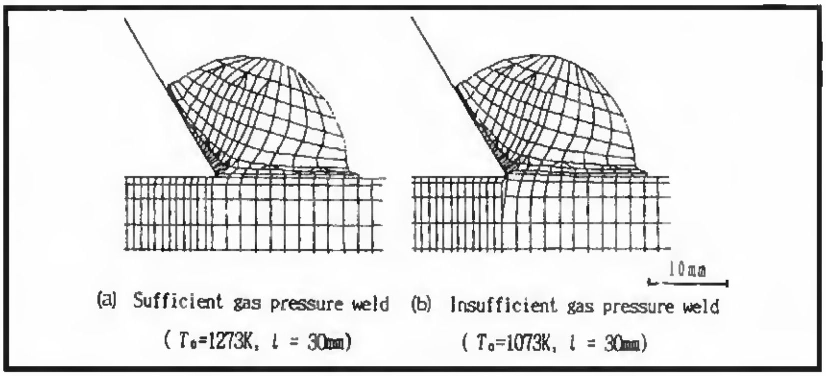

Fig. 11 — Plastic deformations at shearing stage determined by FEM.

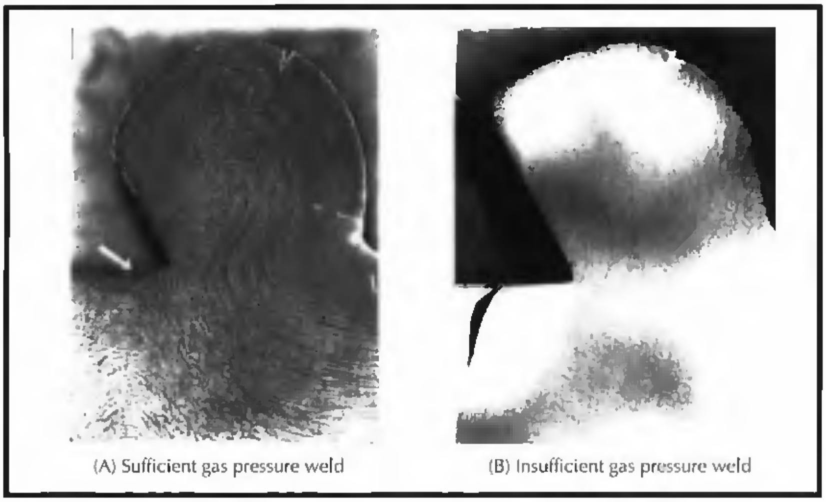

Fig. 12 — Plastic deformations at hot shearing stage.

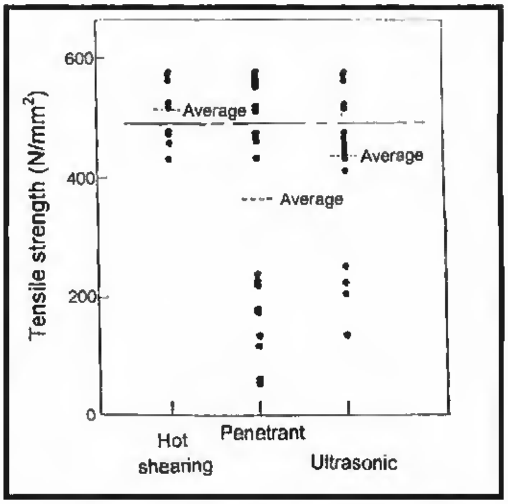

Fig. 13 — Tensile strength of specimens misjudged in each inspection method.

Tables 2 and 3 show the misjudgment ratio (the ratio of contrary judgment between the inspection test result and rupture test result) of each inspection method when the results of tensile and bending tests are adopted as a standard. The number of tensile and bending test specimens were 135 and 100, respectively. In these tables, the white figures are the misjudged pieces. Among these three inspection methods, flash removal by hot shearing was the lowest in the misjudged ratio. Specifically the misjudgment ratio in the tensile test results for the hot shearing method is as low as half the numbers in other methods.

Figure 13 shows tensile test results from misjudged test specimens; that is, the disqualified specimens for each inspection were tested as if they were acceptable specimens. The specified minimum tensile strength (SMTS) of the steel bar is 490 N/mm² as shown in Table 1. Specimens exist that have a tensile strength greater than the SMTS in spite of weld interface fracture. Moreover, the average tensile strength of misjudged specimens inspected by the hot shearing method is greater than the SMTS. However, the average tensile strength of those inspected by ultrasonic and penetrant methods is less than the SMTS, and specimens that have tensile strength of only 50 N/mm² in penetrant inspection or 130 N/mm² in ultrasonic inspection were rated as "qualified specimens." Consequently, hot shearing is a suitable inspection method for joints having extremely low tensile strength.

As a result, it seems clear that flash removal by hot shearing is superior to penetrant and ultrasonic tests as a quality inspection method for gas pressure welds because its ratio of misjudgemnt was low and there was a high tensile strength in the weld even though there was a mistaken judgment.

Conclusions

This report describes gas pressure welding, which is the main joining method for steel reinforcing bars in Japan, and the reliability of flash removal by hot shearing as an inspection method.

Gas pressure welding has been used for welding of rails and steel reinforcing bars since 1953 in Japan. Flash removal by the hot shearing method has been used in rail welding since 1975. Therefore, gas pressure welding with flash removal by hot shearing has been recognized in the fields of both steel reinforcing bar welding and rail welding in Japan.

Moreover, the application of flash removal by hot shearing for gas pressure welding was incorporated into the revised 1994 construction code, *Gas Pressure Welding of Steel Bar,* of the Japan Pressure Welding Society (JPWS). The method has come to be well known. It is expected that the quality of gas pressure welding will get better with more use of this method.

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