S ea Re ce e P e b O e 1 275 MPa Y e d S e a d H D c a e We d

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Abstract:

JFE Steel has developed the high strength shearing reinforcement that reduced the softening induced by heat during welding. The purpose of reducing the softening is to prevent the deformation concentration on the softened area. Softening by the heat effect was the maximum when the steel was heated up to 700–750˚C. The most softened area corresponds to the area heated up to the highest temperature where austenite does not exist in the microstructure. Hardness in the heat-affected zone is raised with the increase of the amount of Mo, V. When the difference in Vickers hardness between the most softened area and the base steel is 70 or less, it bne is by controlling the hardness distribution in the heat-affected zone after welding.

1.

Reinforcing steel in reinforced concrete (RC) can be broadly divided into main reinforcement in the height direction of the structure and shear reinforcement (hoop reinforcement) placed at approximately right angles to the main reinforcement. In earthquakes, the role of the shear reinforcement is to prevent the concrete from reaching a state of brittle shear fracture due to the bending stress generated in the columns and beams. Accompanying the trend toward RC construction in high-rise buildings, recent years have seen an increasing number of examples in which high strength reinforcing steel was adopted not only in the main reinforcements, but also in the shear reinforcements, resulting in heightened demand for high strength steel bars[1)].

Shear reinforcement possessing yield strength of the 1 275 MPa class is the highest strength steel currently adopted. High strength is obtained in this steel by forming tempered martensite, which is achieved by quenching and tempering steel having the proper carbon content.

As shown schematically in . **1**, the construction methods used with shear reinforcement can be broadly classified into two types, one being the spiral type, in which the shear reinforcement is arranged by wrapping the hoops around the main reinforcement in a spiral shape and securing the hoops with hook-shaped parts at its ends, and the welded type, in which a series of individual hoops is arranged in parallel around the main

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reinforcement, and each hoop is closed by welding[2].

The welded type is advantageous from the viewpoint of workability, for example, convenience in transportation of the reinforcing steel, ease in construction of beams, etc. However, when conventional high strength steel bars of 490 MPa class and higher are welded, softening of the heat-affected zone (HAZ) occurs. This is a problem because the strength of the welded joint decreases to a lower level than that of the base material, and ductility is reduced due to the concentration of deformation in this softened area.

Focusing on this condition, the aim in this development was to develop a YS1275 MPa class shear reinforcement that can also be applied to welded type shear reinforcements.

2. v m

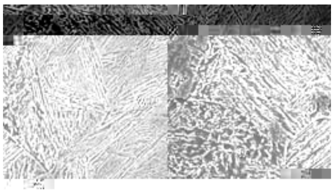
Upset welding is a typical resistance welding method for welded type hoop reinforcements. A schematic image of the welding process is shown in **. 2**, and the appearance of a welded bar immediately after welding and after deburring is shown in **1**.

2

hard phase of martensite forms once again, resulting in higher hardness than in the base material. Conversely, in parts located at a certain distance from the bonding interface, the temperature during welding is less than 700°C. In this temperature region, tempering progresses further than in the base material, forming a softened area which is softer than the base material.

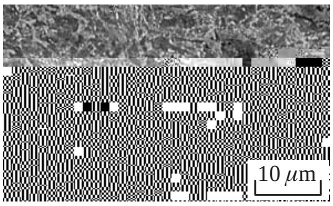
If tensile stress is applied to a low alloy steel having this kind of hardness distribution, deformation will concentrate in the softened area, the strength and ductility of this area will be remarkably deteriorated in comparison with the base material, and it will be impossible to obtain the specified strength characteristics.

As a countermeasure for this problem, the cross-sectional area is increased so as to compensate for the reduction of the strength in the welded joint. This is accomplished by designing the maximum diameter of the joint to be at least 1.4 times greater than the diameter of the base material, in other words, making the diameter of the softened area larger than that of the base material. However, when this measure is employed, the welded joint will have a protruding large-diameter bump at the joint. This causes various problems. In particular, because the cover thickness of concrete[3, 4] is specifi [illegible] Fuji Electronic Industrial Co., L



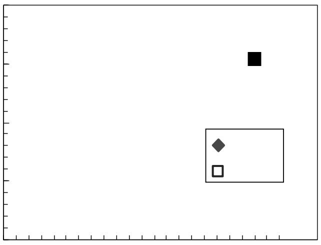
Heated up to 800˚C Hv 606

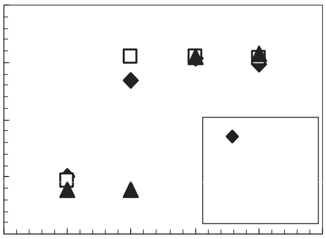
Heated up to 750˚C Hv 568

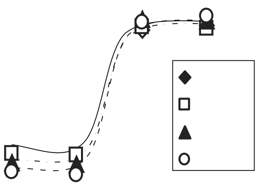


Heated up to 700˚C Hv 400

Photo 3 Microstructure after reproduction test of welding using 0.28mass%C-0.7mass%Cr-0.1mass%V-0.35mass%Mo steel







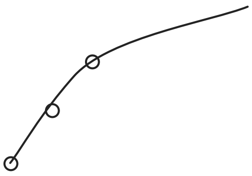


Fig. 6 Effect of alloy elements on the Vickers hardness at the most softened area (Hvs)

phase region could be detected in the microstructure, even when the martensite was present only in a trace amount. Although the results differed depending on the amount of alloy addition, the tempering temperature at which hardness showed the largest reduction was 700–750°C. The softest area is considered to correspond to the part which was heated during welding to around the maximum temperature in the ferrite region.

Based on the results shown in Fig. 5, the effects of the alloying elements on the hardness of the most softened area after the welding reproduction test were arranged as shown in **. 6**. Because increased hardness in the most softened area was confirmed accompanying

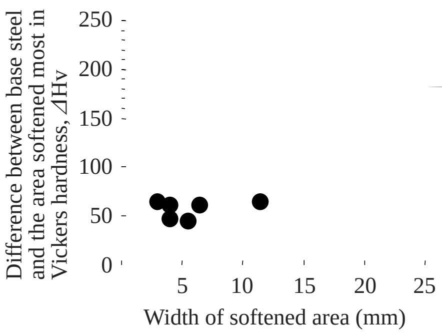


Fig. 7 Effect of the amount of softening and the width of softened area on the occurrence of breaking in softened area

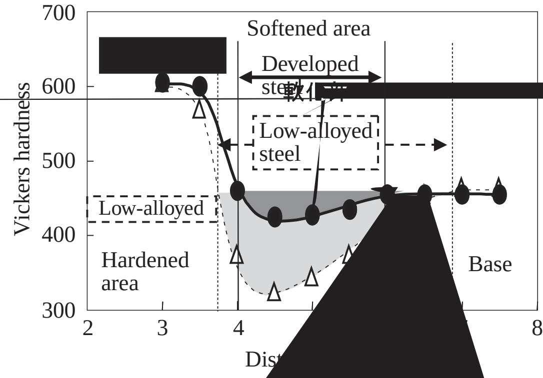


Fig. 8 Hardness distribution around heat-affected zone after upset welding of developed steel and low-alloyed one

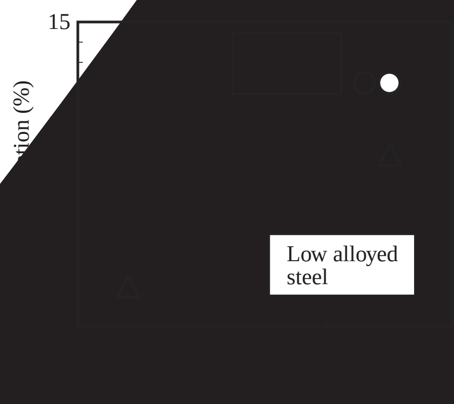


Fig. 9 Tensile property balance in the steel before and after welding

Photo 4 Examples of constructions using developed steel

marks (○) indicate high ductility fracture occurring in the base material, and the X marks show low ductility fracture occurring in the HAZ. Even after welding, breakage takes the form of high ductility fracture in the base material when the difference between the hardness of the most softened part and the base material ΔHv is 70 or less.

The Vickers hardness of base material corresponding to a yield strength of 1 275 MPa class (tensile strength: 1 420 MPa) is approximately 450 Hv. Thus, from these results, it can be understood that hardness of 380 Hv or more is necessary in the most softened part when su[redacted]jected to high temperature tempering.

5. [illegible]

its effectiveness, particularly in RC structures. For example, due to the excellent welded joint shape, which is free of protruding parts, the required cover thickness of concrete specified in the Enforcement Order of the Building Standards Law is easily secured, making it possible to obtain the merits of a compact cross section in the columns and beams.

6.

In order to prevent brittle fracture as increasingly high strength concrete is applied to meet the requirements of taller concrete structures, use of higher strength shear reinforcements in combination with higher strength concretes is effective. On the other hand, as the strength of the shear reinforcements increases, low ductility fracture accompanying softening of the HAZ during welding becomes a problem. To solve this problem, the effects of Mo, V, and other alloying elements and the amount of alloying element addition on softening of the HAZ were investigated. By adopting a composition design based on the results of this study, it was possible to minimize the decrease in the hardness of the softened part due to the effect of heating during welding, and also to control the range of the softened part to a narrow width. As a result, a new steel with an excellent balance of tensile strength and elongation after welding was successfully developed. In the future, JFE Steel and JFE Techno-wire will continue to study and develop high strength shear reinforcements matched to the higher strength of concrete.

1) Shibata, Masataka; Nakazawa, Atsushi; Shiraishi Tamaki; Yamamoto, Noboru; Kosaka, Kiyoshi; Shiga, Katsutoshi. Kawasaki Steel Giho. 1991, vol. 23, no. 2, p. 112–118.
2) Mada, Akiko; Maruta, Makoto. Kajima Gijutsu Kenkyuusho Nenpo. 2003, vol. 51, p. 63–68.
3) Building Standards Act. Article 79.
4) Architectural Institute of Japan. Standard for Structural Calculation of Steel Reinforced Concrete Structures. 2001.