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Experimental tests on construction methods for a joint between concrete wall and steel girder involving long-time onsite welding

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HIGHLIGHTS

- Five construction methods are tested to analyze the effect of long-time onsite welding on concrete.
- Full scale gusset plate is welded to the steel plate embedded in concrete with a total of 18 passes.
- Introduction of a gap around the embedded plate is the most effective in minimizing effect of onsite welding.

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ABSTRACT

To create a joint between reinforced concrete (RC) walls and steel girders in high-rise buildings, the concrete around the embedded plate cannot avoid the damage due to the heat input from a long-time welding (6–48 hours) of the embedded and gusset plates. A literature review showed insufficient research on evaluation of concrete damage due to the welding heat; furthermore, onsite construction workers did not have a clear solution to minimize the damage. In this study, five construction methods with different details are tested to analyze the effect of long-time (approximately 6 hours) onsite welding on the high-strength concrete for the joint between gusset plates and the embedded plate in a high-rise building. Five full-scale specimens with different construction details were tested and analyzed in terms of four items: 1) temperature distribution measurements, 2) compressive strength tests, 3) neutralization tests, and 4) the characteristics of cracks. In this paper, the gusset plates made of SM490 ($f_y = 325$ MPa) were welded over the embedded plates after 28 days of curing of the concrete with a design strength of 55 MPa. Based on the experimental results, it is found that the appropriate selection of construction methods subjected to a long-time onsite welding is to form a gap around the embedded steel plate to minimize the welding heat transfer from the steel plate to concrete.

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1. Introduction

When the core wall first construction method is used for construction of a high-rise building, to make structural joints or connections between steel girders and reinforced concrete (RC) core wall in Fig. 1, the gusset plate is welded to the steel plate embedded in the RC core wall. In this case, the heat input from a long-time welding (up to 48 hours) of the embedded and gusset plates damages the concrete around the embedded plate. In particular, if the thickness of the embedded plate is small and the heat input is large, deformation of the steel plate due to the welding heat causes a gap between the steel plate and concrete. And in addition, the heat input from the long-time welding can cause a high possibility of explosive fracture for high-strength concrete of 50 MPa or more. The similar situations can be found for the installation of belt trusses in a high-rise building where the gusset plate is welded to the embedded plate in the RC mega-column. However, studies on the evaluation of damage to concrete caused by the welding heat of the plate are insufficient and there are no clear design standards for this situation.

The related works reviewed in this study are as follows. Firstly, the heat transfer behavior of the welding was compared and analyzed through finite element analysis [1,2]. As a result, it was possible to realize the state of thermal distribution in the welding. Furthermore, the temperature of welding was predicted using the surface hardness, friction, and surface condition of a plate as parameters [3–7]. Next, the deformation and distortion of welded metal plates were simulated through various analysis programs, which were compared and verified through experiments [8–14].

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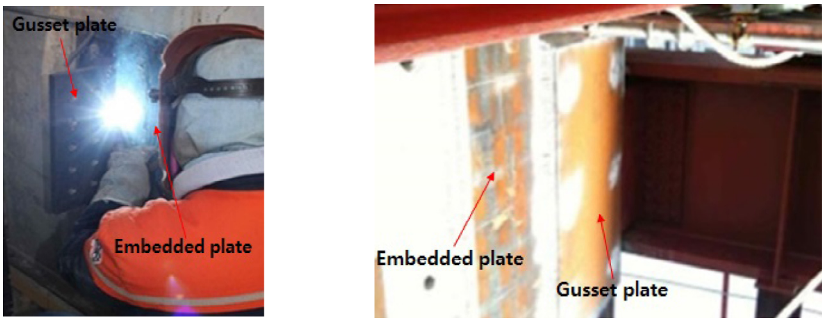

(a) Photograph of welding between embedded and gusset plates

(b) Gusset plate welded to the embedded plate in RC core wall at site

Fig. 1. Connection between steel girder to RC core wall using the gusset plate welded to the embedded plate at site.

Researchers attempted to analyze the experimental results through 3D modeling and, more quickly, through 2D modeling and searched for an optimal solution [15,16]. Furthermore, the welding speed for the butt joint of thin plates and the thickness of the plates were found to affect the distribution of residual stresses [17–20]. In the study, welding deformation of steel plates were estimated. In addition, the temperature variation of steel plates was analyzed through finite element analysis, a calculation formula for the temperature distribution was proposed, and the accuracy of the formula was verified through experimental results obtained from other researchers [21,22].

The amount of concrete expansion was evaluated as the temperature of high-strength concrete containing fly ash and blast-furnace slag was varied (10, 20, and 30 °C). It was demonstrated that shrinkage of the high-strength concrete containing fly ash and blast-furnace slag varies with the temperature variations [23]. Another study predicted the changes in the mechanical properties of steel plates by estimating inner temperature of a plate based on the surface temperature of the plate during welding. The structural stress and strain during the hardening of welds over time were recently evaluated using a finite element analysis program [24,25].

The analysis of the related studies showed that it is difficult to analytically evaluate the damage or cracks on concrete due to the variation of welding heat with different conditions and details. Therefore, to develop and verify effective construction method to minimize the effect of the welding heat on concrete at construction sites, it is necessary to investigate the effect of welding heat on the concrete used for construction methods with different details.

In this study, experiments were conducted with full-scale specimens composed of materials with the same strengths as those of the actual high-rise building structure. Fig. 1 shows the photographs of a gusset plate for the connection of a steel girder with an embedded plate in the RC core at an actual site. In this study, to investigate the construction methods for the connections, specimens for the experimentation are classified into five types. Through full-scale experiments of five construction methods with different details, the effects of long-time welding (the time required for the welding at construction site of a real high-rise building was approximately 6 hours) of the embedded and gusset plates on the high strength concrete were analyzed based on four aspects: 1) temperature measurements, 2) compressive strength tests for concrete, 3) neutralization tests, and 4) pattern of cracks.

2. Outline of experiments

Five full-scale specimens with different construction details for the connections between steel girders to reinforced concrete (RC) core wall are used to analyze effect of the long-time welding heat of embedded and gusset plates on the concrete.

2.1. Fill-scale specimens

In this paper, the compressive strength of concrete for the specimens were 55 MPa, which is frequently used in core wall of high-rise buildings. As shown in Fig. 2, D19 and SD400 ($f_y = 400$ MPa) were used for rebars with dimensions of 1950 mm (width) × 1500 mm (length) × 400 mm (thickness), and the cover thickness of the rebars was 80 mm. Tables 1 and 2 list the test results of mechanical properties of the steel plates and the concrete used for specimens, respectively. The embedded plate was made of SM490 ($f_y = 325$ MPa), having dimensions of 1140 mm (width) × 380 mm (length) × 40 mm (thickness), and the gusset plate attached to the top of the embedded plate was made of the same material, having dimensions of 1020 mm (width) × 260 mm (length) × 40 mm (thickness). As shown in Fig. 3, the gusset plates were welded over the embedded plates after 28 days of curing of the concrete.

The experimental variables were classified into five types: Type A, as the reference specimen (Fig. 2 (a)); Type E (Fig. 2 (b)), in which each corner of the embedded plate has a blue rounded shape; Type D, consisting of a wire mesh, as shown in Fig. 2 (c) (wire mesh #8 is installed between the embedded steel plate and upper rebar, and the gap between the wire mesh and the rebar is 5.75 mm); Type B, with the gap around the embedded plate indicated in green on the plane figure (10 mm width and 40 mm depth; see Fig. 2 (d)); and Type C, coated with a surface hardener, as shown in Fig. 2 (a) (applied to the entire top surface of the specimen after concrete placement).

To measure temperature of the concrete as a function of position, a laser gun (infrared digital noncontact laser thermometer; this device reads the temperature when the heat-generating point is targeted for 3 s) and temperature gauges were used [26,27]. As shown in Fig. 3, two temperature gauges numbered 9 and 10 were installed on the surface of the concrete at 100 mm and 200 mm away from the short side of the embedded plate, respectively. Also, four temperature gauges numbered 5, 6, 7, and 8 were installed on the surface of the concrete along the long side of the plate. To measure the temperature within the concrete, two temperature gauges numbered 3 and 4 were installed 100 mm and 200 mm inside of the concrete (Fig. 4b), respectively. For the long side of the plate, two temperature gauges numbered 1 and 2 were installed 100 mm and 200 mm inside of the concrete, respectively. For each specimen, a total of 10 temperature gauges were installed.

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