# STUDY ON COVERING DEPTHS OF REINFORCED CONCRETE BEAMS COVERED WITH GRC BY FIRE RESISTANT TESTS

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## 1. INTRODUCTION

GRC casting forms have been used as decorative beam or column covers having complicated surface patterns. In these cases, GRC was recognized only as material for decoration. But GRC has been widely used in many construction objects and consequently showed that GRC was not inferior to constructive concrete in many aspects. If GRC can be proved to have no problem about the efficiency of execution, the properties of fire-resistance and those of durability, GRC can be used not only as decorative purpose but also to a part of the constructive material as concrete. If these permanent forms can be practically used, the construction cost may be largely decreased. It is confirmed that integrity of GRC and concrete is important in the case of GRC casting forms so that it becomes key technology that what kind of surface texture should be made inside of GRC as stated in many literature. Fundamental studies on integrity of inner surface of GRC and casting concrete have been made by using many types of GRC casting forms which have been modified inner surface pattern. And also bending test by using real sized beam was made and constructive performance of GRC was observed. From these tests, two types of GRC casting forms were selected as follows. One was unevenly patterned inside and the other was that wire net was buried in half depth inside of GRC. Comparative study was made among reinforced beams using these GRC forms and a reinforced concrete beam without GRC form about fire-proof properties and their results are reported in this paper.

## 2. EXPERIMENTAL METHOD

### 2.1 Specimens

Two types of GRC forms were prepared. As stated above, one was that unevenly patterned inside of GRC hereafter called as the air-cell form, and the other one was that wire net was buried in half depth of GRC hereafter called as the wire-net form. Furthermore, the reinforced concrete beam without GRC form hereafter called as RC specimen was also prepared for comparison.

## 2.2 Manufacturing Method of Specimens

### 2.2.1 GRC Casting Forms

GRC casting forms were manufactured by premix method using the formulae shown as in table1, and specimens having the size of 250×400mm in the section and 1000mm in the length were prepared.

Table 1 GRC Formulae

| Material | Weight Ratio |
|---|---|
| Ordinary Portland Cement | 32 |
| Sand | 61 |
| Micro Silika | 2.0 |
| Super Plastisizer | 1.5 |
| Alkali Resistant Glass fibre | 3.5 |
| Water | 14.5 |

#### 2.2.1.1 Air-Cell Form

The air-cell form was prepared by sticking the air-cell sheet to the steel mold by using tape having adhesive agent on both sides. Premix GRC was cast in the mold and de-molded after hardening. Then the air-cell sheet was peeled off from GRC and circular uneven patterns having 10mm diameter, 4mm depth and 14mm pitch were formed inside of GRC. Structural figure of the air-cell specimen is shown in Fig.1.

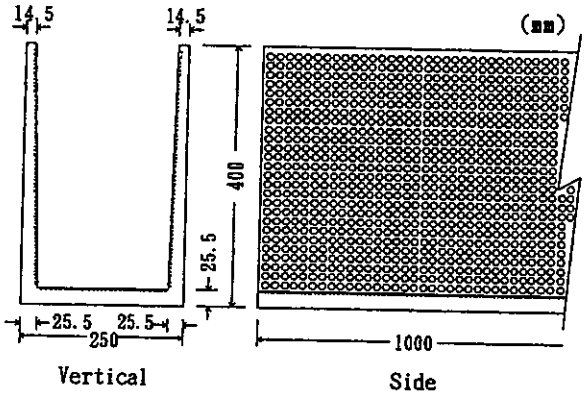


Fig. 1 Section of Air-Cell GRC Casting Form

#### 2.2.1.2 Wire-Net Form

A wooden mold having hinges between the bottom plate and the side plate was prepared. After opening the mold, premix GRC was cast in the half depth to the aimed thickness. Next, wire net having 1.6mm in diameter and 26 ×38mm stitches was pressed and bent by using rectangular lumber

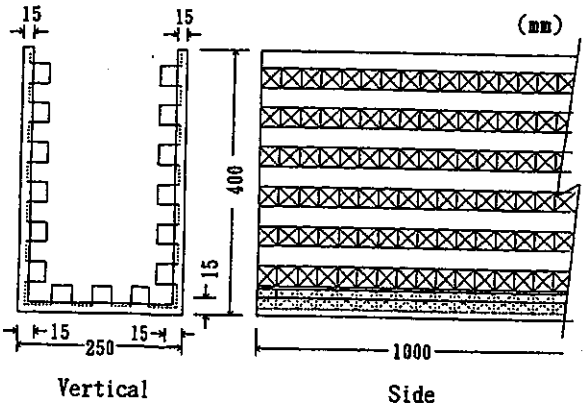


Fig. 2 Sectuin of Wire-Net GRC Casting Form

having 30×30mm section to shape bumpy pattern of 60mm pitch and this wire was put on GRC which was in green condition. And then, the rest premix GRC was cast to the full depth. After about 2hours passed from casting and confirmed that GRC stiffed to a certain extent, the mold was hinged up slowly to prevent collapse of GRC. GRC was cured and de-molded after hardening. Structural figure of the wire-net form is shown in Fig.2.

2.2.2 Arrangement of Steel Bars and Concrete Casting

After fabrication, GRC casting forms were cured in the room temperature for about one month and they were set into the wooden molds which were prepared to prevent concrete leak from the end. And then, thermocouples were set on the fixed position of the steel reinforcement bars and they were placed in the pre-determined place in the GRC casting form. Steel of SD295 D22 type was used as main four reinforcement bars and these bars were arranged in the fixed positions of GRC forms. Steel of SD295 A D10 type was used as stirrups at the interval of 200mm to the longitudinal direction. After arrangement of steel bars, concrete was cast in the mold and GRC specimens were made. Here, concrete formulae is shown in table2. RC specimen was prepared almost as the same manner as GRC specimens. Thermocouples were set on the steel bars and they were placed in the wooden mold. As the same as GRC specimens, RC specimen was prepared by casting concrete after steel bars were set in the mold. Concrete having the same formulae as table2 was used in this case. However covering depth of steel bar is different between GRC specimen and RC specimen. They are shown in Fig.3 and Fig.4. From Fig.3 and Fig.4, covering depth of steel bar in GRC specimens and RC specimen was 20mm and 30mm at the upper part of stirrup, and 30mm and 40mm at the main reinforcement beam which was placed upper part of the specimen, respectively. Here, covering depth shows the distance from the surface of the steel bar to the surface of the specimen so that it contains GRC thickness. Next, concrete slab panel having the size of 600×1900×120mm was prepared by using the same formulae as Table2. This concrete slab panel was opened a

Table 2 Concrete Formulae

| Material | Weight | Characteristics | |
|---|---|---|---|
| O.P.C | 290kg/m3 | Slump | 15cm |
| Fine Aggregate | 844 | Air Content | 4% |
| Coarse Aggregate | 1018 | Compressive Strength | 210kgf/cm2 |
| Admixture | 3.07 | | |
| Water Content | 167 | | |

hole in the center to pull out thermocouples and this slab was fastened to the block shaped specimen by bolt and nut. GRC specimens and RC specimen were cured in the room temperature for one month and dried by using heater to reduce water content below 5%.

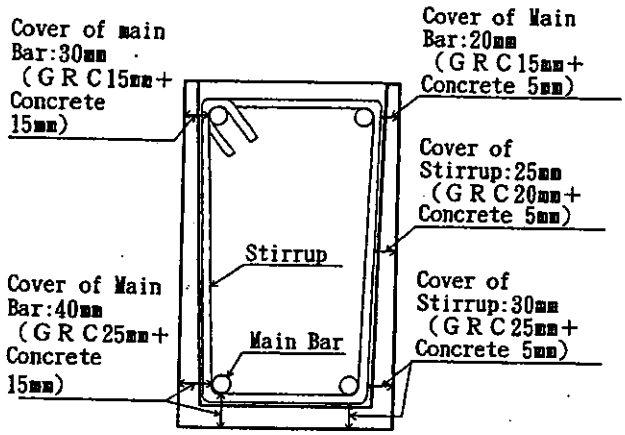


Fig. 3 Cover of GRC Casting Form (Air-Cell Specimen)

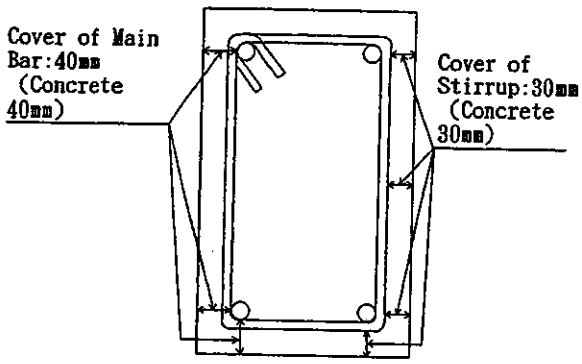


Fig. 4 Cover of Concrete Specimen

## 2.2.3 Position of Thermocouples

Cross section diagrams of GRC specimens, namely the air-cell specimen and the wire- net specimen are shown in Fig.5 and Fig.6, respectively and that of RC specimen is shown in Fig.7. Common side view of these specimens is shown in Fig.8. In Fig.5, Fig.6 and Fig.7, signs of 1,2,3,1',2',3' show the positions of thermocouples which were set on the side of the upper positioned main reinforcement steel bars, and signs

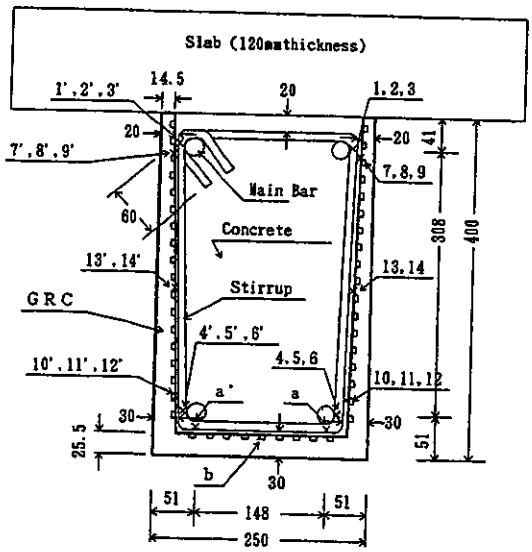


Fig. 5 Cross Section of the Air-Cell Specimen

of 4,5,6,4',5',6' show the positions of thermocouples which were set to the side of the lower positioned main reinforcement steel bars. Signs of 7,8,9,7',8',9' show the positions of thermocouples which were set on the upper side of stirrups and signs of 10,11,12,10',11',12' show the positions of thermocouples which were set on the lower side of stirrup. Signs of 13,14,13',14' show the positions of thermocouples which were set on the middle part of stirrup. Signs of a and a' show the positions of thermocouples which were set on the lower part of lower main reinforcement bars and sign of b shows the position of thermocouple which was set on the lower part of stirrup.

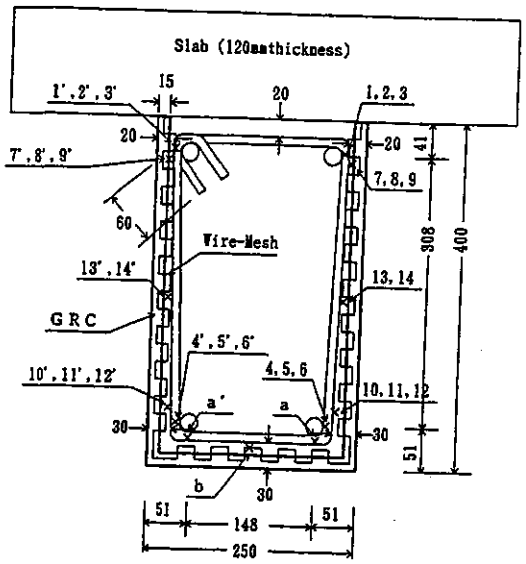


Fig. 6 Cross Section of the Wire-Mesh Specimen

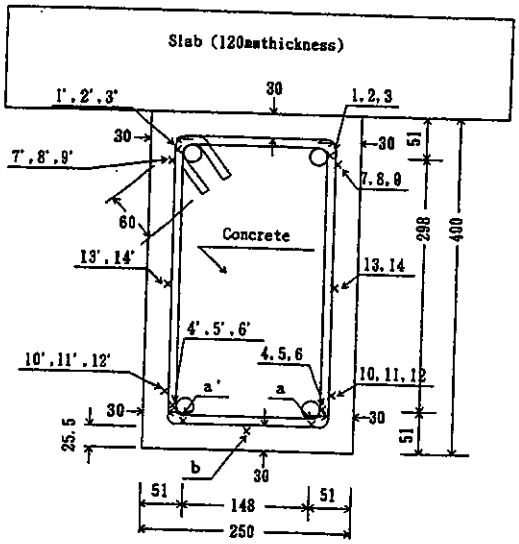


Fig. 7 Cross Section of Concrete Specimen

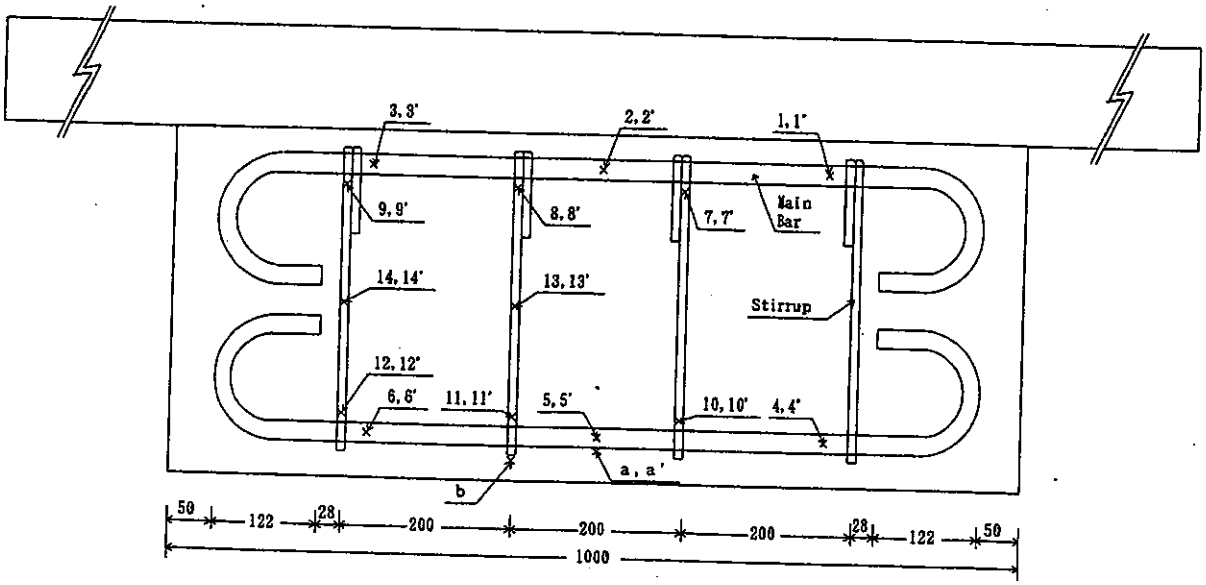


Fig. 8 Common Side View of GRC Specimens and Concrete Specimen

## 2.3 Experimental Method

Fire resistant test was made according to the 2 hour fire resistant test about beam based on JIS A 1304. The furnace which was used in the experiment is shown in Fig.9.

The specimen was heated from left side and right side at the bottom by propane burner. Thermocouples for measuring temperature of furnace were set at 10cm distant from the side of the specimen. Specimens were heated along the heating curve of JIS A 1304 to 2hours. Temperature of steel bar was measured and recorded during and after heating. Confirming the temperature of steel bar declined, specimen was pulled out from the furnace, the appearance of the specimen was inspected especially about the integration between GRC and concrete.

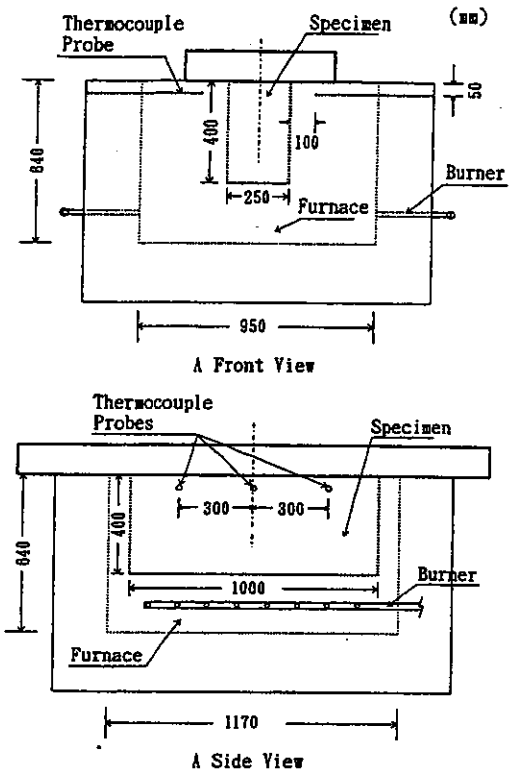


Fig. 9 A Condition of Fire Proof Test

## 2.4 Results

### 2.4.1 Temperature of Steel Bars

Temperature of steel bars during and after heating is shown in Table3. In each case, temperature of steel bar shows maximum degree about 130minutes past from the beginning of heating. In each specimen, temperature of the steel slightly exceeded 500 degree which was the upper limit temperature determined by JIS A 1304.

### 2.4.2 Appearance of Specimen after Heating

Surface appearance of specimen after heating is shown in Fig.10,11 and 12. After confirming the descend of the temperature of steel bars after 2hour heating, specimen was pulled out from the furnace and surface appearance was observed and inspected. In this observation, gap width of crack was measured and recorded about more than 0.2mm width and only sketched about less than 0.2mm width as shown in Fig.10,11 and 12.

Table3 Results of Measuring Temperature of Steel in the Fire Proof Test

| Time | Speci-men | Temperatur(℃) (Average) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Side of Upper Main Bar | Side of Lower Main Bar | Upper Part of Stirrup | Lower Part of Stirrup | Middle Part of Stirrup | Lowest Part of Lower Main Bar | Lowest Part of Stirrup | Temperature in the Furnace |
| | | 1,2,3, 1',2',3' | 4,5,6, 4',5',6' | 7,8,9, 7',8',9' | 10,11,12, 10',11',12' | 13,14, 13',14' | a,a' | b | 41~46 |
| 0min | Air-Cell | 14.4 | 14.3 | 14.3 | 14.2 | 14.6 | 14.5 | 19.7 | 24.0 |
| | Wire-Net. | 5.8 | 6.1 | 5.3 | 6.8 | 6.0 | 8.1 | 7.0 | 47.5 |
| | Concrete | 24.6 | 24.4 | 24.5 | 24.1 | 24.4 | 24.1 | 24.4 | 94.4 |
| 30min | Air-Cell | 92.5 | 110.2 | 146.5 | 118.8 | 117.1 | 115.9 | - | 893.5 |
| | Wire-Net | 97.3 | 127.4 | 132.2 | 161.1 | 147.4 | 124.4 | 178.6 | 864.0 |
| | Concrete | 104.8 | 127.5 | 155.6 | 198.0 | 191.4 | 162.5 | 117.1 | 859.4 |
| 60min | Air-Cell | 165.1 | 270.2 | 263.6 | 296.1 | 255.2 | 266.2 | - | 937.4 |
| | Wire-Net | 146.4 | 331.8 | 250.7 | 369.5 | 310.5 | 329.1 | 387.0 | 945.5 |
| | Concrete | 179.2 | 305.2 | 273.3 | 384.1 | 342.6 | 349.8 | 283.0 | 936.4 |
| 90min | Air-Cell | 230.2 | 412.9 | 344.8 | 432.9 | 359.4 | 409.0 | - | 984.8 |
| | Wire-Net. | 216.1 | 484.7 | 336.0 | 508.1 | 425.2 | 482.6 | 527.7 | 986.5 |
| | Concrete | 249.9 | 444.9 | 357.3 | 508.2 | 440.6 | 484.0 | 424.1 | 999.1 |
| 120min | Air-Cell | 283.7 | 523.7 | 405.5 | 536.1 | 444.9 | 520.1 | - | 1007.1 |
| | Wire-Net | 278.0 | 595.0 | 402.6 | 610.7 | 507.7 | 592.9 | 630.3 | 1011.2 |
| | Concrete | 307.7 | 545.1 | 422.9 | 596.1 | 514.8 | 579.0 | 526.6 | 1034.6 |
| MAX | Air-Cell | 294.0(130min) | 558.9(137min) | 409.6(123min) | 555.2(130min) | 456.2(127min) | 556.8(138min) | - | 1007.1(120min) |
| | Wire-Net | 295.1(136min | 623.1(133min) | 410.1(126min) | 626.2(128min) | 517.6(126min) | 621.1(134min) | 641.5(126min) | 1011.2(120min) |
| | Concrete | 324.9(136min | 575.6(137min) | 431.5(126min) | 607.2(127min) | 523.1(126min) | 590.1(136min) | 560.5(138min) | 1034.6(120min) |
| 150min | Air-Cell | 275.0 | 545.1 | 324.5 | 514.7 | 393.6 | 544.4 | - | 320.6 |
| | Wire-Net | 287.2 | 594.7 | 352.8 | 569.4 | 452.7 | 594.5 | 569.0 | 352.1 |
| | Concrete | 315.9 | 560.6 | 372.1 | 545.2 | 451.0 | 557.3 | 550.9 | 302.9 |
| 180min | Air-Cell | 230.5 | 463.5 | 247.7 | 422.1 | 310.1 | 464.0 | - | 62.9 |
| | Wire-Net | 253.7 | 496.2 | 280.3 | 462.5 | 361.3 | 498.0 | 475.0 | 90.4 |
| | Concrete | 279.6 | 482.7 | 307.7 | 452.6 | 373.0 | 471.4 | 481.8 | 203.2 |

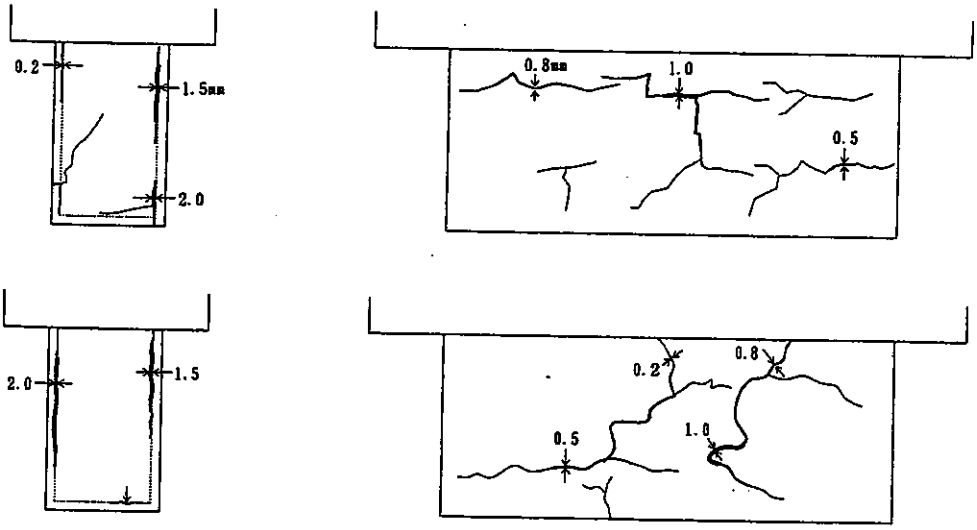


Fig. 10 Appearance of the Air-Cell Specimen after the Fire-Resitant Test

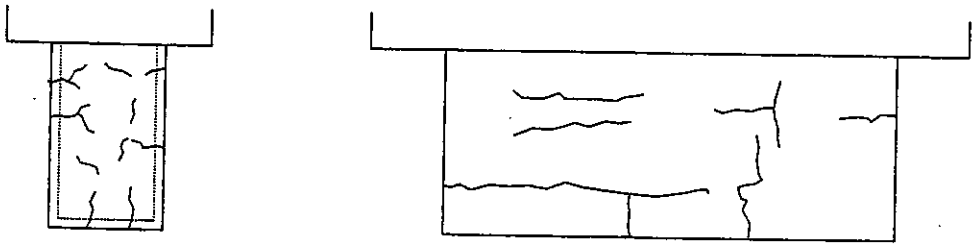

Fig. 11 Appearance of the Wire-Net Specimen after the Fire-Resitant Test

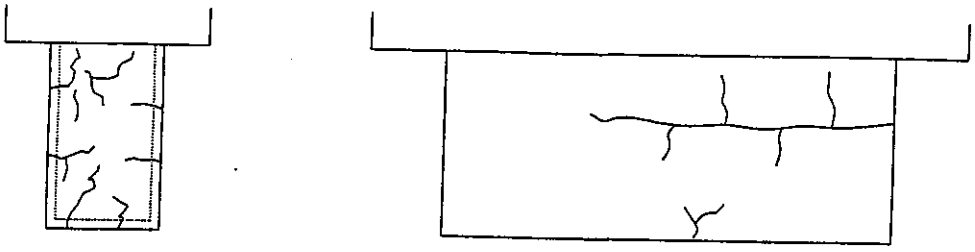

Fig. 11 Appearance of the Wire-Net Specimen after the Fire-Resitant Test

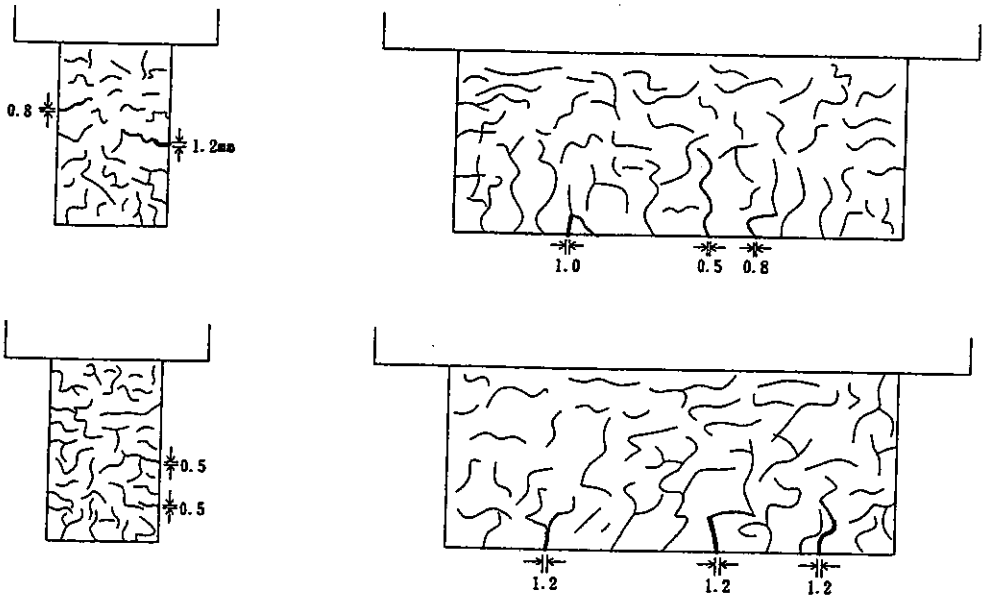


Fig. 12 Appearance of the Concrete Specimen af the Fire-Resitant Test

## 3. DISCUSSION

Covering depths of steel bars in GRC specimens and RC specimen were different in the same place of steel bars as shown in Fig.3 and Fig.4. Tendencies of heat variation at the same covering depths of GRC specimens and RC specimen are shown in Fig.13,14,15 and 16. The reason why the temperature in Fig.13 is lower than those of other graph is that the slab was heated only from the bottom and not became high temperature so that the slab quenched the specimen and the temperature of the upper bars showed lower value than that of other places. RC specimen showed higher temperature of the steel bar than GRC specimens because that the steel bar of the RC specimen was positioned 10mm lower than that of GRC specimen and hard to receive quenching effect from the slab. From Fig.14,15 and16, GRC specimens and RC specimen showed

the resembled tendencies of temperature rising. The reason why the air-cell specimen showed lower temperature is that the gap between GRC and concrete was partially generated and this worked as heat insulator. From the inspection of appearance after heating, GRC specimen showed no harmful defects even though GRC and concrete separated partially in the air-cell specimen as shown in Fig.10,11 and 12. In the case of the wire-net specimen, the adhesive condition between GRC and concrete was superior than other specimens. There was no separate in the interface between GRC and concrete and no wide cracks on the side surface of the specimen.

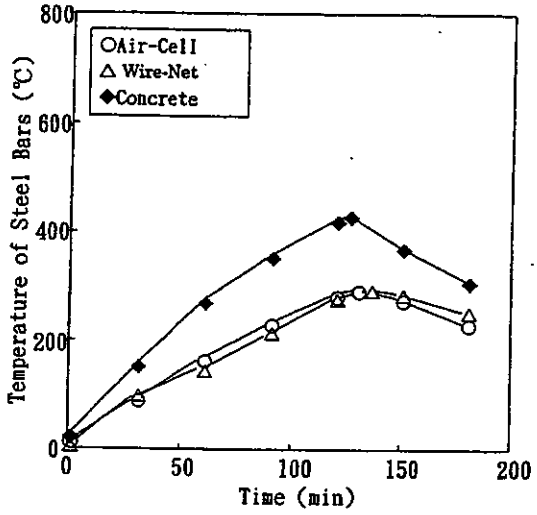


Fig. 13 Covering Depth of 30mm at the side of the Upper Part

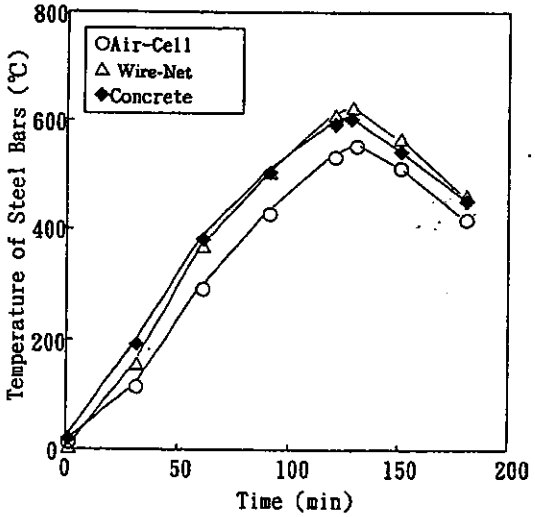


Fig. 14 Covering Depth of 30mm at the side of the Lower Part

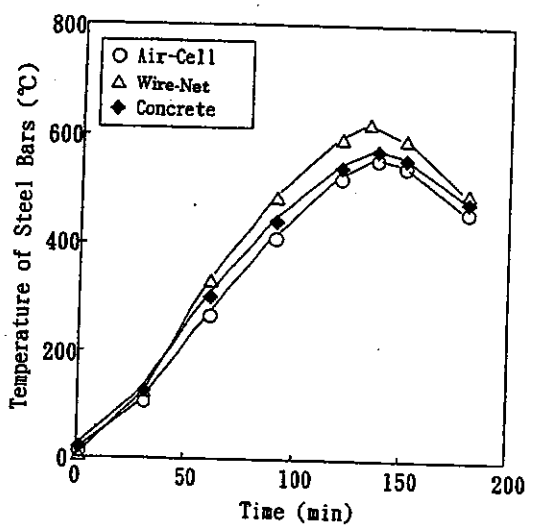


Fig. 15 Covering Depth of 40mm at the side of the Lower Part

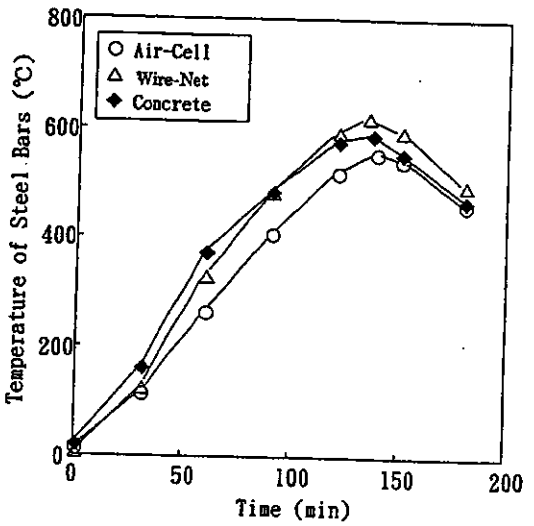


Fig. 16 Covering Depth of 40mm at the bottom of the Lower Part

## 4. SUMMARY

Two types of GRC permanent forms which were improved adhesive efficiencies between GRC and concrete were prepared. By using these GRC forms, RC beams were made and tested their fire resistant abilities compared with RC beam without GRC form and the following results were obtained.

(1) From the results of measuring temperature of the steel in the beam during the heating test, GRC specimens showed almost resembled tendencies of rising temperature of steel bars as RC specimen at the position of the same covering depths. GRC specimens showed lower temperature than RC specimen at the side of the upper positioned steel bar. Furthermore, the air-cell specimen showed lower rising temperature curve than other specimens.

(2) From the inspection of specimens after heating, cracks which connect to seriously harmful to the structure of beam were not observed in every specimens. Especially, the wire-net specimen showed less defects compared to other specimens.

From these results, it can be said that each type of GRC casting forms behaves as a body of concrete so that GRC can be included as covering depth of concrete.

**Acknowledge)**

I wish to acknowledge to the members of GRC association Japan.

**References)**

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