Shear Transfer of Reinforced Concrete at Elevated Temperature

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1.INTRODUCTION

Reinforced concrete (RC) structures in a nuclear power station such as a containment vessel and structural members supporting reactor vessel are designed assuming that they may be subjected to high temperature. In the design code, it is specified that the temperature of concrete shall not exceed the limitations and thermal loads shall be taken into account. Flexural behaviour of reinforced concrete subjected to high temperature over 100°C has been investigated in recent studies(Kanazu,1987), but shear behaviour is not yet understood very clearly. So, in the present study, shear test using push-off type specimens are performed to investigate shear behaviour of reinforced concrete subjected to high temperature and examine the experimental data.

2.TEST PROGRAM

The diagrammatic sketch of the specimen used is shown in Fig.1. The area of shear plane is about 450cm^2. Test parameters studied in this program are, reinforcement ratio in shear plane (p), compressive stress normal to shear plane (σ_N) and temperature of shear plane (θ) (as shown in Table 1). The compressive strength of concrete at test is about 500kgf/cm^2 and maximum size of coarse aggregate used is 20mm. The reinforcing bars used in all the experiments are of 19mm deformed bars having a yield strength of 3700kgf/cm^2. Triangular wedges (depth about 5mm) are fixed on the bottom and top faces of the specimen to introduce initial crack in the shear plane. And also 4 bolts are embedded in the specimen at location as shown in Fig.1. The specimens are cured under wet gunny bags for a month

Table 1 Test parameters

reinforcement ratio (p)	1.27% (2D19),	2.55% (4D19),	3.82% (6D19)
normal stress (σN)	0 kgf/cm², -10kgf/cm²		
temperature (θ)	normal, 100℃, 200℃		

after removal of forms and then air-dried. The specimens are tested after allowing six months air-drying.

The specimens are initially cracked and heated by panel heaters to the desired testing temperature raising the temperature at the rate of 20°C per hour and maintained at that temperature for about 2 days. Then the specimens are gradually loaded to failure. The compressive stress normal to shear plane is introduced to the specimens after they are cracked and is controlled to keep a constant value during heating and loading by the spring for creep test.

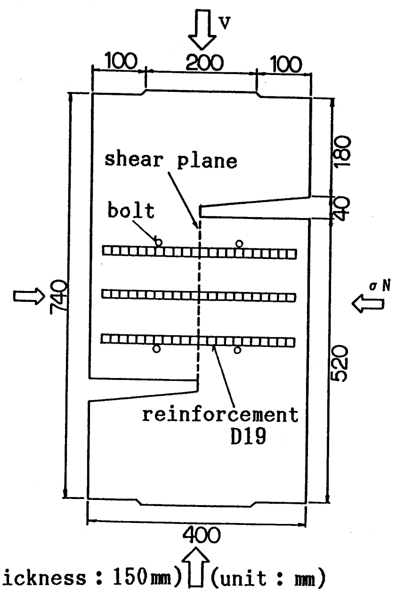

Fig.1 Configuration of specimen

The lateral separation and slip at the shear plane is measured on both faces of the specimen in addition to strain of reinforcement. By fixing 4 displacement transducers to the embedded bolts on each face of the specimen (i.e. a total of 8), we obtain a total of 4 values each for the lateral separation and slip. The average of these 4 values is used in further analysis. The temperature of specimens is measured using 22 thermocouples to make sure that the temperature is constant and uniform.

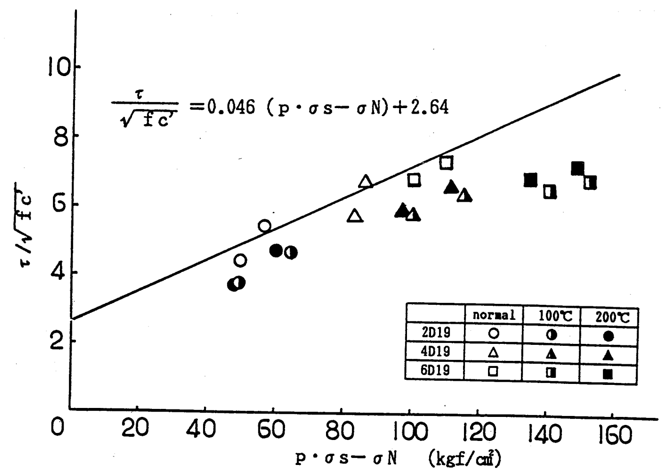

Fig.2 Relationship between the shear strength ratio and compressive stress acting transverse to the shear plane

3.EXPERIMENTAL RESULTS AND DISCUSSIONS

Fig.2 shows the relationship between the shear strength ratio ($\tau/\sqrt{fc'}$: maximum shear stress divided by square route of compressive strength of concrete) and the net compressive stress acting transverse to the shear plane ($p\cdot\sigma s-\sigma_N$). Yamada et al. have proposed the equation in Fig.2 for the variation of shear stress with normal stress (Yamada,1981). It can be observed from Fig.2 that our data for normal temperature coincide fairly well with Yamada's equation. But the shear strength ratios of specimens at high temperature condition are lower than that at normal temperature condition. Also, there is little difference between the data at 100°C and 200°C. The slope of the line represented in Fig.2 can be looked upon as a sort of coefficient of friction resisting shear slip. Judging from the experimental results, this coefficient of friction has a tendency to decrease at the high temperature condition.

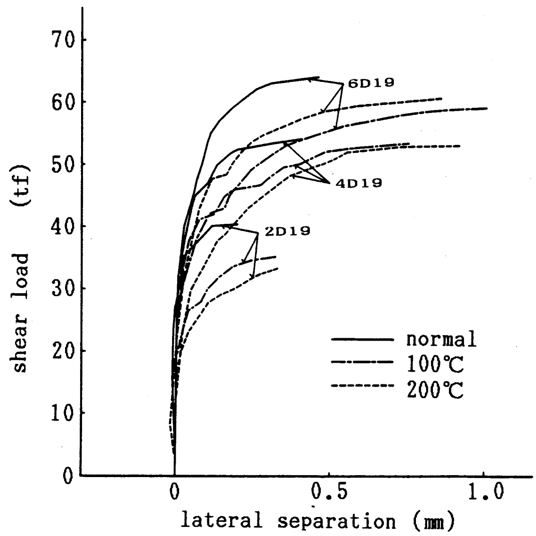

Fig.3 Relationship between the shear load and the lateral separation(σ_N=0kgf/cm^2)

The variation of concrete strength (fc') and the Young's modulus of steel (Es :σ_s= Es · ε_s) with temperature has been taken into account when plotting the data for 100°C and 200°C (Kanazu,1987).

Fig.3 shows the relationship between the shear load and the lateral separation at the shear plane at loading when the compressive stress normal to the shear plane is zero (σ_N=0kgf/cm^2). The maximum shear loads of specimens heated to 200°C are about 10 percent lower than those at normal temperature but almost equal to those of specimens heated to 100°C. The lateral separation scarcely increases until the shear load approaches its peak. The total lateral separation (i.e. the sum of the separation at initial cracking, heating and loading) at maximun shear stress is 0.43mm at normal temperature, 0.75mm at 100°C and 0.93mm at 200°C, irrespective of the reinforcement ratio (p) and the normal stress (σ_N). So the value increases according as the temperature increases. It has been reported by Yamada that at normal temperature the lateral separation at the maximum shear load is 0.4mm irrespective of concrete strength and reinforcement ratio when the maximum size of coarse aggregate is under 20mm and the specimen is initially cracked (Yamada,1981). The experimental results obtained here conform to this earlier finding. However, the reason why the lateral separation becomes large at high temperature is not yet clarified. Maybe the condition of the shear plane changes when it is subjected to high temperature.

Fig.4 shows the relationship between the shear load and the slip along the shear plane at loading when the compressive stress normal to the shear plane is zero (σ_N= 0kgf/cm^2). The slip along the shear plane at high temperature increases instantly compared to the lateral separation (Fig. 3). It seems that there is some relation between the slip and the lateral separation before loading. The larger the lateral separation of specimen before loading is, the earlier we have an increase in the slip along the shear plane. The values of the lateral separation rise under heating are 0.07mm at 100°C and 0.21mm at 200°C. The slips along the shear plane at the maximum shear load reach 0.42mm at normal temperature, 0.64mm at 100°C and 0.85mm at 200°C. Thus at any temperture the values of slip are almost same as those of the lateral separation.

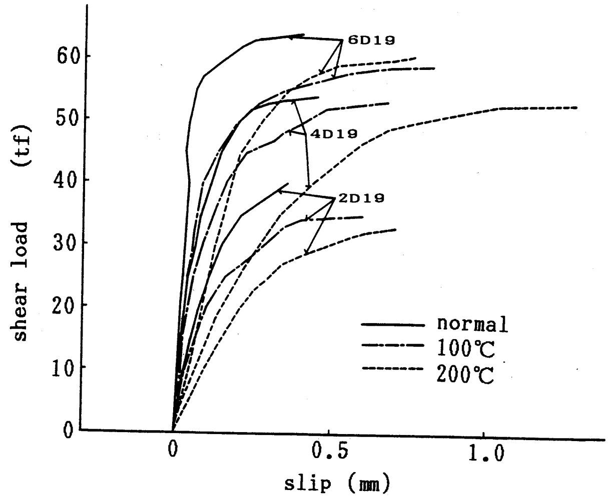

Fig.4 Relationship between the shear load and the slip (σ_N=0kgf/cm^2)

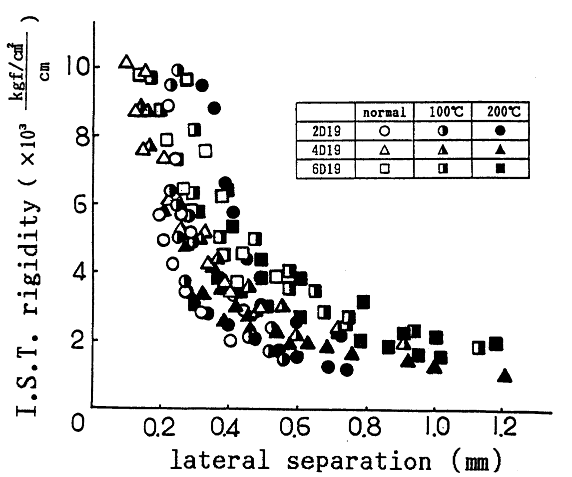

Fig.5 Relationship between the interface shear transfer rigidity and the lateral separation

Fig.5 shows the relationship between the shear stress which causes unit slip along the shear plane (named interface shear transfer rigidity) and the lateral separation at the shear plane. The lateral separation in the figure is the total value of that at introducing crack, heating and loading. Judging from the figure, despite of some variance the experimental data have a hyperbolic distribution irrespective of reinforcement ratio (p), compressive stress normal to shear plane (σ_N) and temperature (θ). It seems that even at high temperature up to 200°C there is the same relationship between the interface shear transfer rigidity and the lateral separation as that at normal temperature.

As part of the further research program, it is proposed to carry out tests using specimens subjected to tensile stress normal to the shear plane.

4. CONCLUSIONS

The conclusions obtained from the present study are as follows.

1) The maximum shear loads of specimens heated to 200°C are about 10 percent lower than those at normal temperature, but almost equal to those of specimens heated to 100°C.

2) The total lateral separation increases according as the temperature increases.

3) At high temperature up to 200°C, there is the same relationship between the interface shear transfer rigidity and the lateral separation as that at normal temperature.

REFERENCES

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