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INFLUENCES OF SURFACE CONFIGURATIONS OF REINFORCEMENT ON BOND BETWEEN CONCRETE AND REINFORCEMENT

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INFLUENCES OF SURFACE CONFIGURATIONS OF REINFORCEMENT ON BOND BETWEEN CONCRETE AND REINFORCEMENT

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Abstract

This paper discusses the influences of surface configurations of reinforcing bars on the bond characteristics between concrete and reinforcing bars based on the detailed results of pull-out forces and relative displacement involved in pulling out bars from concrete. Twenty two different bars of 26-mm diameter, which are formed by machining plain bars with systematically varying inclination angles in the lug sides, lug heights, and lug spacings, were used.

The influences of the surface configurations of reinforcing bars on the bond characteristics can be evaluated by a proposed bearing area coefficient and shearing area coefficient.

1. Foreword

Concrete and steel, which is used as reinforcement for concrete, complement each other in resisting external forces together and thus reinforced concrete constitutes an effective structural element. One reason for this effectiveness if that reinforcing bars with projections and indentations on the surfaces strongly bond with the concrete. In order to secure the bond characteristics of a bar within a certain level, the Japanese Industrial Standards specifies the range of lug height, h, lug spacing, l_n, gaps of lug, s, and angle with bar axis, θ, as shown in Fig. 1. Since the influences of these factors on the bond characteristics are inter-related, however, a procedure for assessing the overall influences of these factors should be established. The authors have already proposed a bearing area coefficient and a shearing area coefficient as factors useful in making such assessment.

In this paper, a brief description of these factors and a discussion on the influences of surface configurations of reinforcing bars on the bond characteristics between concrete and reinforcing bars based on the detailed results of pull-out forces and relative displacement involved in pulling out bars from concrete. Twenty two different bars of 26-mm diameter, which were formed by machining plain bars with systematically varying inclination angles in the lug sides, lug heights, and lug spacings, were used.

2. Materials Used, Test Specimens and Method of Testing

The test specimens, as shown in Fig. 2, were 20-cm cubes of concrete each with a reinforcing bar embedded horizontally at the middle and with a spiral reinforcement of 6-mm diameter bar in the cube to prevent abrupt failure of the concrete. The length over which deformations were provided on each bar was 91 mm from the free end. This length was considered to be the embedded length of the bar, l. Specimens were cured in water until the age of 7 days at which time they were subjected to pull-out tests. The test method was to pull the reinforcing bar and reactive the force at 3 points as shown in

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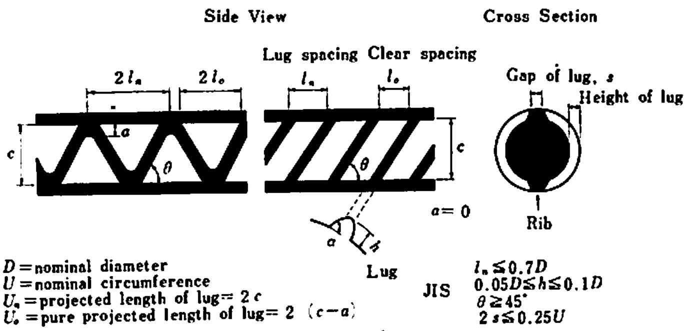

Fig. 1 Various factors related to surface configuration of deformed bar and JIS specifications

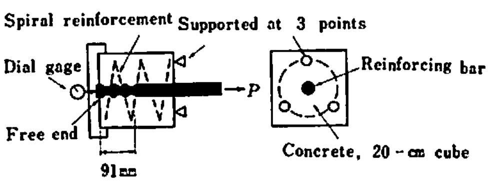

Fig. 2 Specimen and method of testing

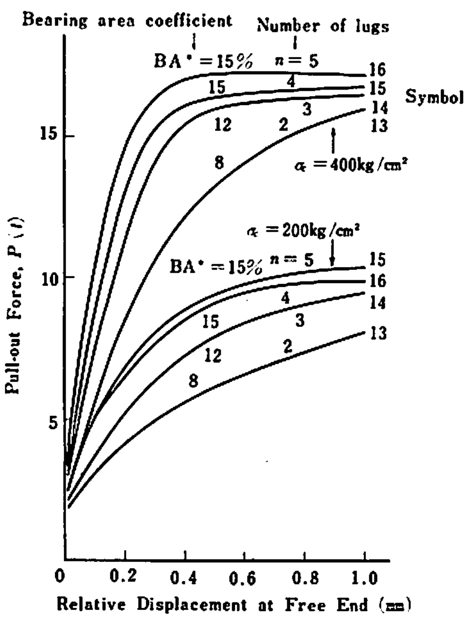

Fig. 3 Pull-out force and relative displacement ($h = 3$ mm)

Fig. 2. Relative displacement between concrete and the reinforcing bar at the free end was measured.

Two types of concrete with compressive strengths of approximately 200 kg/cm^2 (average of 8 batches 188 kg/cm^2) and approximately 400 kg/cm^2 (average 416 kg/cm^2) at 7 days were used. The maximum size of aggregate was 25 mm and high early strength portland cement was used. Slump of concrete was approximately 5 cm.

The reinforcing bars used were those machined from plain bars of 28- to 32-mm diameters as shown in Photo. 1. A total of 6 groups and 22 configurations as indicated in Table 1 were considered. For convenience of machining, ribs used in ordinary deformed bars were not provided and consequently, the so-called gaps of lugs were nil. Therefore, the spacings between lugs were enlarged by varying the widths of lugs without changing the actual clearances between lugs and the bearing areas and shearing areas of lugs were correspondingly adjusted. It was confirmed through preliminary tests that no differenee in the bond characteristics of reinforcing bars without ribs was detected when these measures were taken.

3. Bearing Area Coefficient and Shearing Area Coefficient

Relations between pull-out forces involved in

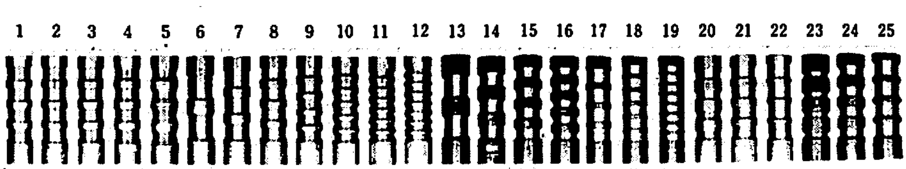

Photo. 1 Reinforcing bars used in tests

Table 1 Surface Configurations of Reinforcing Bars Used in Tests (D=26 mm)

Symbol	α	h (mm)	n	l_n (mm)	l_o (mm)	h_e (mm)	BA* (%)	SA (%)	Variables	
1	90°	2	4	23	15	2.0	10.0	75	α	
2	60°									
3	45°									
4	30°									
5	15°									
6	45°	2	2	46	30	2.0	5.0	75	l_n	h
7			3	30	20	2.0	7.7	77		
8			4	23	15	2.0	10.0	75		
9			5	18	12	2.0	12.8	77		
10			6	15	10	2.0	15.4	77		
11			7	12	8	1.6	15.4	77		
12			8	11	7	1.4	14.7	74		
13	45°	3	2	46	28	3.0	8.0	75	l_n	
14			3	30	18		12.3	74		
15			4	23	14		15.0	75		
16			5	18	11		15.0	75		
17	45°	1	4	22	16	1.0	4.9	78	l_n	
18			6	16	11		6.7	74		
19			8	11	8		9.8	78		
20	45°	2	4	23	10	2.0	10.0	50	l_o	h
21					15			75		
22					20			100		
23	45°	3	4	23	9	1.8	9.6	48	l_o	
24					14	2.8	15.0	75		
25					19	3.0	16.0	102		

pulling out reinforcing bars from concrete and the relative displacements at free ends are illustrated in Fig. 3. This figure shows the results for a constant lug-height and with four variations of number of lugs, that is, lug spacing. This figure clearly shows that the relative displacement is smaller for narrower lug spacing. This is because the bearing area for narrower lug spacing is larger and as a result the stress acting on concrete due to pull-out force decreases. The results in Fig. 3 when replotted as a relation between bearing stress and relative displacement is shown in Fig. 4. Figure 5 shows the relation between the bearing stress and the shearing stress when the relative displacements reach 0.1 mm and 1 mm for all reinforcing bars with α of 45°. It should be noted that these results were obtained in a concrete with strength of 400 kg/cm². The same trend was indicated for concrete with strength of 200 kg/cm². From these figures, it may be seen that the relative displacement between reinforcing bar and concrete depends greatly on the bearing stress for relatively small displacement and that the magnitude of the bearing stress for a given relative displacement is roughly constant. Further more, Fig. 5 indicates that for large relative displacement the displacement is more dependent on the shearing stress rather than on the bearing stress. This

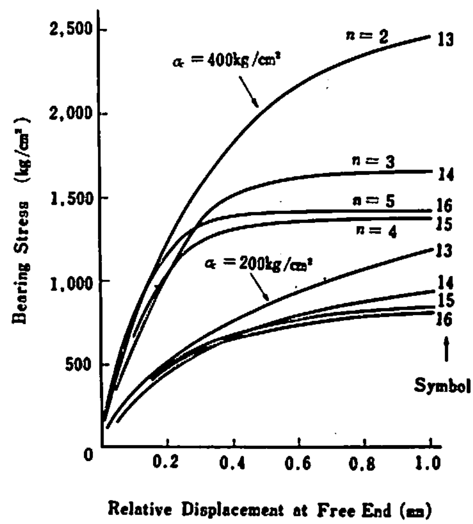

Fig. 4 Relation between bearing stress and relative displacement

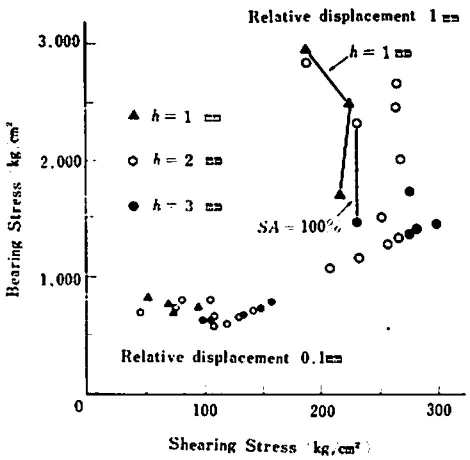

Fig. 5 Relation between bearing stress, shearing stress and relative displacement (σ_c $=400$ kg/cm²)

is due to sudden increase in relative displacement when the localized shearing stress acting on the concrete between two adjacent lugs exceeds certain limit.

Bearing stress and shearing stress are defined by Eq. (1) and Eq. (2) as

$$\sigma_b=(P_0-P_b)/B \doteqdot (\tau_0-\tau_b)/BA^* \quad (1)$$

$$\tau=(P_0-P_b)/S \doteqdot (\tau_0-\tau_b)/SA \quad (2)$$

where

σ_b = bearing stress
τ = shearing sterss
B = bearing area
S = sheartng area
P_0 = pull-out force
P_b = force transmitted to concrete without involving lugs
τ_0 = bond stress $=P^0/Ul$
U = nominal circumference of reinforcing bar
l = embedded length
τ_b = bond strength not dependent on lug (20 kg/cm² and 14 kg/cm² for concrete strength of 400 kg/cm² and 200 kg/cm² respectively)
BA^* = bearing area coefficient $=\frac{h_e}{l_n}\times\frac{U_0}{U}$
h_e = effective height of lug (see 4)
l_n = lug spacing
U_0 = pure projected length of lug (see Fig. 1)
SA = shearing area coefficient $=\frac{l_0}{l_n}\times\frac{U_n}{U}$
U_n = projected length of lug (see Fig. 1)
l_0 = clear distance between lugs (see Fig. 1)

Since part of the pull-out force is transmitted by pure bond, frictron or other forces between the reinforcing bar sutface and concrete, the total pull-out force, P_0, less a given vatue, P_b, was assumed to act on the concrete as a bearing force. The bearing stress and shearing stress defined above are thus only for convenience in assessing the bond characteristics of bars. Figure 5 shows the results obtained from these equations. These results clearly indicate that the influences of the surface configurations of reinforcing bar on the bond characteristics can be evaluated by bearing area coefficient and shearing area coefficient. In essence, it shows that the bond characteristics is better the larger the two coefficients.

4. Effective Height of Lug

The narrower the lug spacings and the higher the lug height, the larger is the bearing area coefficient and generally the bond characteristics will become better. When the clear distance between lugs becomes too small in comparison with the lug height, the bearing reaction force at the base of a lug cannot be transmitted readily into the surrounding concrete. It thus becomes impossible to effectively utilize the entire height of the lug. Consequenly, in case of lug height being 20% of clear spacing or greater, twenty percent of clear spacing was assumed as the effective height of lug, h_e, in tests using retnforcing bars of diameter of 51 mm.

In these experiments using bars of 26-mm diameter, relations between bearing stresses calculated using lug height, h, and l_0/h for relative displacement of 0.1 mm are shown in Fig. 6. In this case also, it is thought suitable for 20% of the clear spacing to be adopted as the effective limit of lug height.

5. Inclination Angle of Side of Lug and Angle between Lug and Bar Axis

Test results for inclination angles of the sides of lugs varied between 15° and 90° are as given in Fig. 7. These results show that for small relative displacement, the relative displacement is larger for smaller the values of the angle. When the angle is more than 45°, however, its effect is not very great. This is probably caused by the increased tensile forces acting in the direction perpendicular to the bar axis due to the wedge action for the small angles, but this

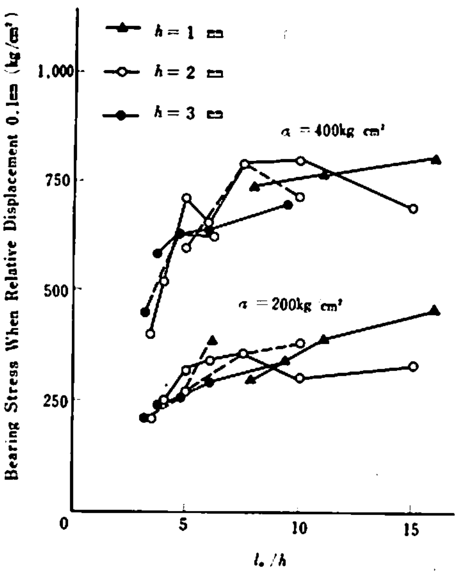

Fig. 6 Relation between l_0/h and bearing stress (h used in lieu of h_e)

influence becomes comparatively small when the angle is 45° or more. Furthermore, it is indicated that the influence of the angle formed between lug and bar axis is small when the angle is in the range of 45° to 90°. In an actual deformed bar, unless an especially large arc is provided at the base of the lug in attempting to improve fatigue properties, the inclination angle is generally more than 45° and the angle between lug and bar axis is required to be not less than 45° in the JIS specifications. Consequently, it is probably unnecessary to consider the influences of the inclination angle of the side of a lug and the angle formed with the bar axis in evaluating the bond characteristics of deformed bars.

6. Relative Displacement and Splitting

When deformed bars are used, there are cases in which bond between reinforcement and concrete is broken due to cracks produced in the concrete along the reinforcement. This cracking is caused by the tensile forces acting in a direction perpendicular to the bar axis due to the deformations along the bar surfaces. Therefore, surface configurations which generate large tensile stress in concrete are not of desirable kind. Hence, pull-out tests were carried out with coverage of 24 mm at one side and without any spiral reinforcement.

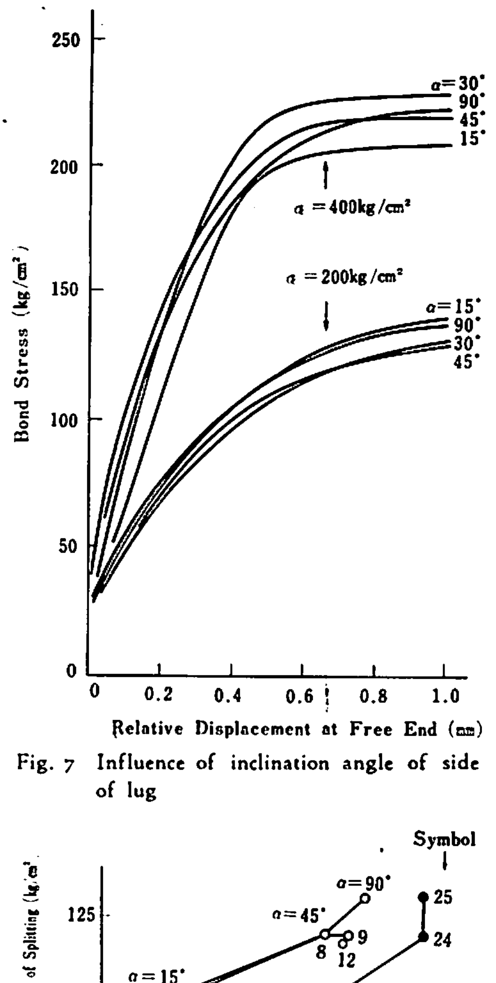

Fig. 7 Influence of inclination angle of side of lug

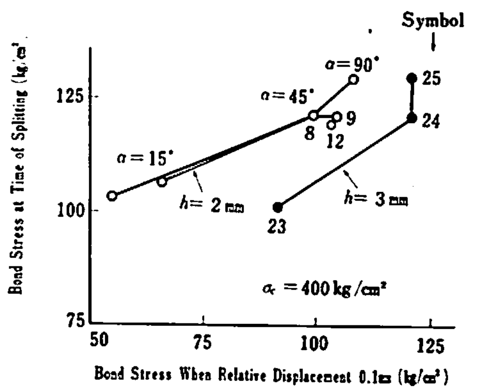

Fig. 8 Relation between relative displacement and splitting force

Since concrete was splitted along the reinforcing bars in all of the specimens, the relation between the bond stress at time of splitting and bond stress when relative displacement reached 0.1 mm were obtained and illustrated in Fig. 8. From this figure, with equal heights of of lugs, a tendency for larger splitting resistance for smaller relative displacement is clearly recognized. Also bars with large bearing area coefficients and shearing area coefficients generally introduce smaller splitting forces to concrete. When these two coefficients were equal, bars with large lug spacings tend to increase the splitting forces from the individual lugs were strong.

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