A STUDY ON SHEAR STRENGTH OF CONCRETE UNDER DIRECT SHEAR TEST

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1. Introduction

Concrete shear strength is of practical interest. For example, the NATM (New Austrian Tunneling Method) required knowledge of shear strength of concrete. Joints between dissimilar media under shear forces or normal forces parallel to existing cracks are also cases where shear strength is needed. The present work has two main objectives. The first is obtaining shear strength of different types of lightweight aggregate (LWA) and normal weight concretes. And the second is to find out the relation between shear strength and roughness of a sheared section. Double shear test was selected as a testing method for the experimental study.

2. Test programs

The experimental work consisted of four types of concretes. Table 1 shows different types of concrete together with Water/Cement (W/C) ratio and quantity of specimens for each series of tests. LWA used in this study were made from expanded shale with density 1.9g/cm^3 and 1.58g/cm^3 for fine and coarse aggregates respectively. The selection of mix proportions for concrete specimens is presented in Table 2. Photo 1 shows loading arrangement of the double-shear test. A beam specimen was symmetrically positioned within a shear device. The shear device consists of two parts, a base and a top part. The outer surface of shearing edges of the top part is coincided with the inner surface of shearing edges of the base. The intersection of this surface and the beam is the tested section that is the section used to calculate shear strength. Along two tested sections there were strain gauges glued on the surface of the beam. These gauges were used to monitor and adjust eccentric loading. Monotonic, force-controled loading was applied with speed of increment of shear stress of 0.1N/mm^2 per second.

3. Test result and discusion

Failure of all beams was brittle. At first load increased without any sight of cracks. Then near the peak load, visible cracks were seen followed by sudden brake of specimen into pieces.Damaged specimens were divided into two groups, namely succeeded and failed. About 75% of specimens succeded the test where damaged sections coincided with calculated section. The remained speciments failed the test. They had unfavorable crack pattern where cracks were curvy or inclined in certain angle. Damaged section of these specimens is very much deviated from calculated area, which yields unreliable results.

Table 1 Detail of beam specimens

Series name	W/C (%)	Qtt. (unit)	Description
NSNG-1	86	12	Normal weight concrete.
NSNG-2	58	12	
NSNG-3	43	12	
NSLG-1	86	12	LWA concrete of normal fine and LW coarse aggregates
NSLG-2	58	12	
NSLG-3	43	12	
LSNG-1	86	12	LWA concrete of LW fine and normal coarse aggregates
LSNG-2	58	12	
LSNG-3	43	12	
LSLG-1	86	12	LWA concrete of LW fine and coarse aggregates
LSLG-2	58	12	
LSLG-3	43	12	

Table 2 Concrete mix proportions

Series name	W/C (%)	s/a (%)	Weight per unit volume (kg/m^3) W	C	LS	S_N	S_L	G_N	G_L	SP	AF	VI	G_{max} (mm)
NSNG-1	86	48	165	192	162	892	-	977	-	2.667	0.381	1.143	15
NSNG-2	58			287	81					3.810			
NSNG-3	43			381	0					4.953			
NSLG-1	86	48	165	192	162	892	-	-	587	1.143	0.381	1.143	
NSLG-2	58			287	81					2.286			
NSLG-3	43			381	0					3.429			
LSNG-1	86	48	165	192	162	-	652	977	-	0.762	0.381	1.143	
LSNG-2	58			287	81					1.524			
LSNG-3	43			381	0					2.286			
LSLG-1	86	48	165	192	162	-	652	-	587	0.762	0.381	1.143	
LSLG-2	58			287	81					1.905			
LSLG-3	43			381	0					3.048			

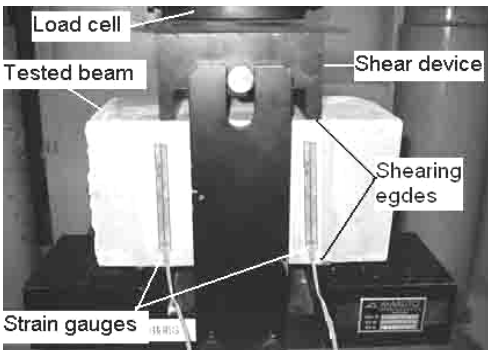


Photo 1 Test arrangement

3.1 Shear strength vs. compressive strength

Fig.1 shows plots of shear strength versus compressive strength for all selected specimens. Relation between shear strength and compressive strength was established by fitting all data points using least-square linear regression analysis. The resulting straight line is shown in Fig.1. Shear strength can be expressed by formula:

$$t_c = 0.1 f_c' + 2.03 \qquad (1)$$

where, t_c : shear strength (N/mm^2)

f_c': compressive strength (N/mm^2)

3.2 Influence of W/C ratio

Fig.2 shows relation between W/C ratio and average shear strength. Decrease W/C ratio resulted in increase of shear strength. When W/C ratio was higher than 0.6, both LWA and normal concrete had the same rate of strength increment. Shear strength of normal concrete was about 1.2 to 1.3 times higher than that of other LWA concretes. When W/C ratio was less than 0.6 shear strength of concrete increased more sharply.

4. Surface roughness

Surface of a tested section of specimens was scanned using the needle 3D scanner (Roland Pix-4). The scan pitch was 0.1 mm. Fig.3 shows examples of images created by a CAD program using scanned data. Fig.4 shows waveform of surface at scan line.Average roughness R_a defined in JIS B 0610 standard was defined by the following formula:

$$R_a = \frac{1}{L}\int_L \left| f(x) \right| dx$$

Fig.5 shows relation between roughness and compressive strength. When strength is low, roughness is high. This means few coarse aggregates damaged because roughness is mainly contributed by the existence of non-damaged coarse aggregate on a surface. As concrete strength increases, roughness decreases quickly. LSLG had the lowest roughness. NSLG had higher roughness than that of LSLG when strength of concrete in a range between 20 N/mm^2 to 40 N/mm^2, however for higher strength its roughness is as low as LSLG roughness. LSNG had shear strength quite closed to normal weight concrete. In general, NSNG had the highest surface roughness.

4. Conclusion

The following conclusions can be drawn from the study: (1) Model for shear and compressive strength relationship was established for all types of concrete. (2) Shear strength increased when W/C ratio decreased. The rate of increment was significant when W/C ratio smaller than 60%. (3)The source of shear strength reduction in LWA concrete is because of its low roughness. NSNG concrete had the highest average roughness follow by LSNG concrete, which had very closed roughness to that of NSNG concrete. Roughness of NSLG concrete was intermediate value between roughness of NSNG and the lowest roughness value belong to LSLG concrete. Limit crack size could improve shear strength of LWA concrete.

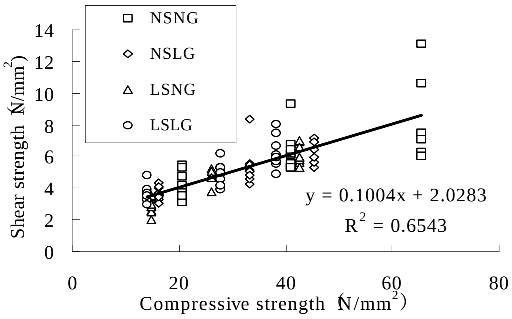


Fig.1 Shear and compressive strength relation

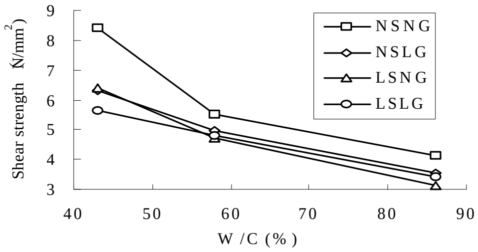
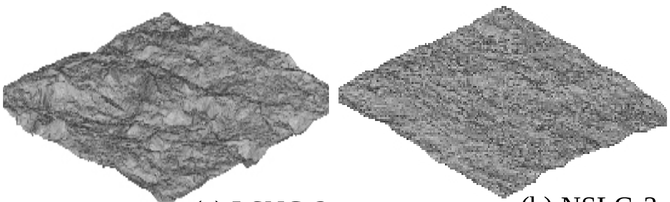


Fig.2 Relation between shear strength and W/C ratio



(a) LSNG-3 (b) NSLG-3

Fig.3 Computer images of sheared sections

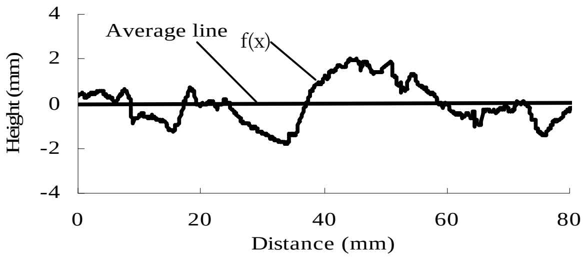


Fig.4 Surface at scanned line

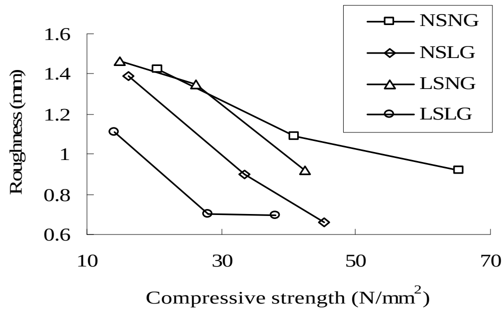


Fig.5 Roughness vs. compressive strength