Bonding between Aggregates and Cement Pastes in Concrete

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Abstract: This investigation was carried out to study the effect of aggregate roughness on ITZ (interfacial transition zone) at same water/cement ratio and the influence of silica fume on the bond strength. On the experimental side, two types of aggregates (limestone and granite) were used, which were prepared with broken surface. Cement (Type I) was used with same w/c ratio for all batches. In order to study the effect of silica fume on the bond, the same mixes were produced with 8% silica fume. Three different tests were performed: “pull a part”, Brazilian test and compressive strength test. The specimens for Brazilian and compressive strength were tested after 28 days, while the “pull a part” specimens were tested after 29 days. The result showed that the bond strength is influenced by the surface roughness of aggregate. For the same mix, limestone recorded higher bond strength than granite. Moreover, the bond strength is increased by adding the silica fume.

Key words: ITZ, limestone, granite, silica fume, bond strength, “pull a part” test.

1. Introduction

Concrete is the most widely-used material in construction over the world. It has been considered as three-phase composite: bulk cement paste, aggregate and the ITZ (interfacial transition zone) between the two phases [1-3]. The discovery of the ITZ was made in the early 1950s, when French engineers were involved in vast rebuilding program [4]. This included hydraulic structures, in which they investigated the use of different type of rocks to support the structures or to use it in concrete as aggregates [4]. Since that time, attention focused on the ITZ and numbers of researchers have found that many concrete properties are controlled by this zone. In addition, the ITZ layer is known to be the weakest link effecting both durability and mechanical properties of concrete [5]. It was suggested [3, 6] that the weakness of the ITZ may be as a result of the following: (1) development of a higher porosity than in the bulk matrix; (2) formation of larger crystal particles of the hydration products; (3) deposition of calcium hydroxide crystals with a

preferential orientation on the interface. The elastic modulus of concrete is affected by the interfacial transition zone which represented by volume of voids and micro cracks [1].

It has been established [1, 7] that, under compressive load, cement paste and coarse aggregate when individually subjected to load exhibit a linear behaviour until fracture. On the other hand, concrete shows inelastic behaviour, as shown in Fig. 1.

2. Experimental Procedures

2.1 Materials

Two types of aggregates (limestone and granite) have been used; These two types were chosen because they are the most common types of aggregate rocks used in concrete. Also, they have different physical and chemical properties and different reaction with cement paste. The used cement was ordinary Portland cement (Type I). Also, slurry form of silica fume was used with 8% replacement, associated with Fosroc Aurocast 200 super plasticiser.

Fig. 1 Stress-strain relations for cement paste, aggregate and concrete [7].

2.2 Preparation of Specimens

Aggregate cubes $100 \text{ mm} \times 100 \text{ mm} \times 100 \text{ mm}$ of limestone and granite were prepared for “pull a part” test. A 20×20 cross section aggregate prisms were cut out from the parent rocks. Then, these prisms were cut out using hydraulic press to get cubes with broken surface which reflect the normal surface roughness of aggregates used in concrete.

2.3 Measurements of Surface Roughness of Aggregate

The roughness of aggregate cubes was measured using surface profilometer and the typical roughness for each aggregate type are illustrated in Figs. 2 and 3.

Fig. 2 Typical roughness of granite aggregate.

Fig. 3 Typical roughness of limestone aggregate.

The roughness was measured on small length of aggregate cubes and the roughness values, as below:

$$Ra \text{ (granite)} = 14.22 \mu\text{m}$$

$$Ra \text{ (limestone)} = 11.74 \mu\text{m}$$

3. Mix Design

Two types of mixes were designed, concrete and mortar mixes. The first mix is for measuring the compressive and splitting tensile strength (indirect tension), while the second mix is for measuring the direct tensile strength.

Both mixes were designed using same water/cement ratio that is in order to compare the performance of different materials at the same w/c ratio.

3.1 Concrete Mix Design

Four concrete mixes were performed and the mixes were designed by BRE (Building Research Establishment) method which relates compressive strength to w/c ratio [8]. The details and quantity of materials for each mix are listed below:

- Mix A: cement + limestone aggregate;
- Mix B: cement + granite aggregate;
- Mix C: cement + limestone aggregate + 8% silica fume;
- Mix D: cement + granite aggregate + 8% silica fume.

3.2 Mortar Mix Design

Two types of mortar mixes were designed and the

mixes proportion are shown in Table 2.

3.3 Casting

3.3.1 "Pull a Part" Test Specimens

The specimens were casted in Perspex moulds, where two 6-mm diameter bolts were inserted into both ends of the mould and fixed using nuts. As illustrated in Fig. 4, the length of extended bolts inside the mould is 30 mm as it has been recommended [5] to ensure that the specimens will not fail at the paste/rod boundary.

3.3.2 Brazilian and Compressive Strength Tests Specimens

The concrete mixes were casted in cylinders and cubes to test in splitting and compressive strength tests.

3.4 Curing Condition

The same curing condition was provided for all specimens, so after de-moulded, the specimens were put in water tank, at temperature until tested after 28 days.

3.5 Test Methods

Different tests were performed in this research to measure the strength of hardened concrete mainly the bond strength. These tests are: "pull a part" test (direct tension), Brazilian test (indirect tension) and compressive strength test. Hence, there is no specific test to measure the bond, so the first two tests were used to measure the bond and relate these values to compressive strength.

Table 1 Material proportions for concrete mixes.

Mix No.	Cement		Water		Fine aggregate		Coarse aggregate		Silica fume (8%)		Superplasticiser (0.3/100 kg cement)	
	kg/m ³	kg/mix	kg/m ³	kg/mix	kg/m ³	kg/mix	kg/m ³	kg/mix	kg/m ³	kg/mix	kg/m ³	kg/mix
A, B	477.77	3.92	215	1.763	680.89	5.58	1,021.34	8.37	-	-	-	-
C, D	477.77	3.92	215	1.449	680.89	5.58	1,021.34	8.37	76.44	0.628	1.577	0.0132

Table 2 Material proportions for mortar mixes.

Mix No.	Cement		Water		Fine aggregate		Silica fume (8%)	
	kg/m ³	kg/mix	kg/m ³	kg/mix	kg/m ³	kg/mix	kg/m ³	kg/mix
M1	477.77	0.55	215	0.204	680.89	0.784	-	-
M2	477.77	0.55	215	0.204	680.89	0.784	76.44	0.088

Fig. 4 Schematic representation of “pull a part” specimen.

Fig. 5 Tensile strength with different aggregate and mortar.

All the specimens were tested after 28 days, except the “pull a part” test which was done after 29 days.

4. Results and Discussion

4.1 “Pull a Part” Test Result

Four groups of specimens have been tested, while each group contains four specimens. The average strength are shown in Fig. 5.

According to the result of “pull a part” test, specimens prepared with limestone recorded higher bond strength than that of granite specimens; This may be due to the chemical reaction between the limestone aggregate and cement paste.

However, the surface roughness of limestone, as it was measured by the profilometer, is lower than that of granite aggregate, which indicates that the bond

strength is not direct function in the surface roughness, but it also depends on some other factors, as it was reported [5].

In addition, the bond strength has increased significantly for all the specimens prepared with silica fume. The increase of bond strength for limestone was about 53%, while for granite it was about 45%.

4.2 Brazilian Test Result

Four group of concrete cylinders were tested in splitting tensile strength, and the average strength for each group are illustrated in Fig. 6.

From Fig. 6, the splitting tensile strength for granite is slightly higher than the tensile strength of limestone specimens with and without silica fume.

The effect of silica fume on increasing the bond was

Fig. 6 Average splitting tension strength for each mix.

Fig. 7 Average compressive strength for each mix.

not as high as that in direct tension (“pull a part”), where the increase of strength was about 25% and 27% for limestone and granite, respectively.

4.3 Compressive Strength

Two concrete cubes were tested for each mix. Fig. 7 showed the average compressive strength for each mix.

The result of compressive strength showed the same manner of the Brazilian test result. The only different is the strength values, as well as the effect of silica fume on the strength.

4.4 Accuracy

The accuracy of the result of “pull a part” test may be affected by different factors, including:

- the leaking of mortar around the aggregate cubes, which may make the bond stronger than what it should be;
- the load rate during the testing, which may lead to get inaccurate result because the Hounsfield tensometer is manually operated which make it difficult to control the loading rate;
- the variety of cross section of aggregate cubes, which may slightly effect the calculation of stress.

5. Conclusions

From the result of the experimental work performed for this project, some conclusions are represented below:

- (1) Limestone performed better than granite in “pull

a part” test, and the opposite in Brazilian and compressive strength tests;

(2) The roughness of granite cubes used in this project is higher than limestone cubes. However, the limestone has higher bond strength, which may be due to the chemical interaction between the limestone and cement paste;

(3) Silica fume improved the tensile strength for pull apart and Brazilian tests by about 50% and 25%, respectively. However, the compressive strength was improved by less than 20%;

(4) Different modes of failure were observed at the ITZ in “pull a part” test. However, some specimens failed in same paste far away from the ITZ.

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