PERFORMANCE AND CHARACTERISTICS OF BOND BETWEEN HIGH STRENGTH CONCRETE AND STEEL REINFORCEMENT

Nasir SHAFIQ
Associate Professor, Department of Civil Engineering, Universiti Teknologi PETRONAS, Malaysia.

M Fadhil NURUDDIN
Associate Professor, Department of Civil Engineering, Universiti Teknologi PETRONAS, Malaysia

Salmia BEDU
Postgraduate Student, Department of Civil Engineering, Universiti Teknologi PETRONAS, Malaysia.

*Corresponding author Email: nasirshafiq@utp.edu.my

ABSTRACT

This paper presents and discusses the experimental results on investigating the performance and characteristics of bond strength induced between high strength concrete and embedded steel reinforcement. Four different mixes containing different combination of admixtures and portrayed 28 days compressive strength in the range of 60 and 100 N/mm^2 were investigated. Experimental results showed trend of significant refinement in the bond strength between concrete and embedded steel bars with the increment in compressive strength from 60 to 100 N/mm^2. Particularly the concrete contained microwave incinerated rice husk ash (MIRHA) and a dosage of superplasticiser resulted in more than 10% higher bond strength as compared to that concrete incorporated silica fume and the same dosage of superplasticiser. Similarly, concrete contained a dosage of used lubricating oil instead of the dosage of superplasticiser showed the higher bond strength as compared to the normal strength concrete.
Key Words: rice husk ash, high strength concrete, silica fume, bond strength

1.0 INTRODUCTION

In the modern construction of mega structures such as high-rise buildings and long-span bridges, there is a great tendency for the application of high strength concrete (HSC). It is because of the reason that various structural components in such structures i.e. lower floor columns are subjected to very high magnitude of loads. Application of high strength concrete helps to reduce the size of such components to some extent thus the weight of the building structure is reduced too. Since last two decades many successful efforts have been made to develop concrete with grade 50 and above [1].

Ramazan (2005) used blast furnace slag aggregates (BFSA) to produce high-strength concretes [2]. The concrete mixes were developed with total binder (cement plus admixture) content of 460–610 kg/m^3. Silica fume content of 10% was used as partial replacement to cement with a dosage of superplasticiser that was added to improve the workability.

Low toughness is one of the serious shortcomings of high strength concrete. There have been made some efforts to increase the toughness of HSC by incorporating short discontinuous fibres in it [3].

Various kinds of mineral admixtures such as fly ash, silica fume, and ground granulated blast furnace slag are commonly used in high strength concrete, which cause the densification of concrete internal structure. In this manner, the failure mechanism could be modified so that the concrete exhibits a more brittle behaviour. Graceila (2007) reported that the incorporation of rice husk ash (RHA) in concrete increased the strength to a large extent at lower water/binder ratio. The analysis of the failure mechanism indicates a tendency for more brittle failure behaviour in RHA concretes [4].

Silica fume (SF) contents of 150–250 kg/m^3 (10–30% of the total cement content) were used

for producing ultra high strength concrete with the very low water/binder ratio. High pore-filling of concrete is achieved by the glassy surface smoothness and strong pouzzolanicity of silica fume [5 Ahmed, 2009].

This paper presents experimental investigation of development of compressive strength and bonding characteristics of very high strength concrete containing silica fume (SF) and microwave incinerated rice husk ash (MIRHA). The principal objectives of the study were to investigate the compressive strength of various type of concrete at different ages and to determine the bond characteristics of concrete with embedded steel bars.

2.0 EXPERIMENTAL INVESTIGATION

2.1 MATERIAL PROPERTIES AND MIXES

Ordinary Portland cement (OPC) conforming to BS 12-1996 was used for the concrete mixtures. SIKA Malaysia supplied the silica fume. Rice husks were obtained from Bernas that were incinerated in a microwave at a constant temperature of 800^0C; the resulting ash was called microwave incinerated rice husk ash (MIRHA). Mined sand with a specific gravity of 2.65 and fineness modulus of 2.64 was used as the fine aggregate (FA), while gravels of specific gravity 2.72 were used as coarse aggregate (CA). A naphthalene sulphonate based superplasticizer (SP) supplied by SIKA Malaysia was used to obtain the desired slump of 60 ±5mm, whereas water binder ratio was kept constant as 0.30.

From a series of trial mixes, four concrete mixes were prepared based for 28 days target strength of 80-100 MPa. Two of them incorporated silica fume and the other two were contained microwave incinerated rice husk ash. Details of mix proportions are in Table-1:

Gravel, sand, cement, silica fume and/or MIRHA were first mixed dry in a 100 kg mixing capacity concrete mixer for a period of 2 min. The superplasticizer was then mixed thoroughly with the mixing water and added to the mixer. After adding water into the mixer it was further mixed to another 2 minutes. The fresh concrete was poured in the slump cone as per specifications given in BS BS1881Part-102. The fresh concrete was then poured into 150mm steel cubes for determination of compressive strength at the age of 3, 7, and 28 days, 3 cubes were cast for every age of testing. For determining the ultimate bond strength; cylindrical concrete samples of 150mm in diameter and 300mm high were made. A 16mm diameter high-tensile steel bar was embedded 200mm deep in the middle of the concrete samples as shown in Figure-1.

2.2 SPECIMEN TESTING & ANALYSIS

Compressive strength of 150mm cubes was determined by testing them under compression force using universal testing machine (UTM). The rate of loading was 2kN/s and 3 cubes were tested at the age of 3, 7, and 28 days. Compressive strength, f_{cu} was determined by dividing the failure load with the cube surface area.

For pull-out test; cylindrical samples were placed and fixed at the bottom seat of the UTM. The 16mm steel bar was clamped into the upper jaw of the machine, and then the pull-out force was applied at the rate of 0.4kN/s in the steel bar in upward direction. The slip in the bar was measured using a linear variable differential transducer (LVDT); it was recorded in a USB drive at every increment of 0.1kN in loading. At the end of testing of each specimen; load versus slip data was analyzed. Bond strength, f_b and the relative slip, S_r was calculated for each of the data using the following equation:

$$f_b = \frac{P}{(\pi\phi)L} \tag{1}$$

$$S_r = \frac{S}{L} \tag{2}$$

Where:

P = Pull-out load at every increment, N

ϕ = Diameter of embedded steel bar, mm

L = Bar embedment length, mm

f_b = Bond strength, MPa

S_r = Relative slip, mm/mm of embedment

S = Measured slip at every load increment, mm

3.0 RESULTS AND DISCUSSION

Compressive strength of all four mixes was determined at the age of 3, 7 and 28 days. Figure-2 shows the results of compressive strength obtained from experimental investigation. At the age of 3-days, all mixes achieved more than 50MPa strength,

600 OPC/MIRHA concrete attained a value of 67.8MPa in comparison to the corresponding silica fume mix 600OPC/SH that reached to a value of 64MPA, which about 7% lower than the MIRHA concrete. At the age of 7-days there was an average increment of about 29% in compressive strength was obtained. There was high increment in strength in550OPC series of concrete mixes. At the age of 28-days, there was observed high percentage of increase in silica fume concrete with respect to 7-days strength. For 550OPC/SF concrete an increment of about 26% was observed as compared to the 7 days strength, this concrete achieved a value of 85MPa at 28-days. Where in 550OPC/MIRHA concrete an increment of about 8% was obtained with respect to its 7-days strength; the concrete reached to a value of 79MPa. Similarly in 600OPC/SF concrete there was very high increase in strength as it achieved 105MPa which was about 43% higher than its 7-days strength. On the other hand, there was only 15% increment in strength of 600OPC/MIRHA concrete was observed when it achieved average compressive strength of 94MPa at the age of 28-days. In general SF concrete showed 7-11% more compressive strength as compare the 28-days strength of the corresponding MIRHA concrete. It was observed that the 600OPC concretes exhibited 20-23% more compressive strength as compared to the strength of the 550OPC concretes.

Figure-3 shows the bond strength, f_b and relative slip, S_r relationship for all four concrete mixes. Relative slip, S_r is defined as the slip per unit embedment length of bar. It was observed that the f_b-S_r curve for silica fume concrete within elastic range is steeper than that of the MIRHA concrete. Bond stiffness, K_b is determined by measuring the slope of straight line within elastic region of the curve. The steeper curve of silica fume concrete means higher stiffness than that of the MIRHA concrete. The bond stiffness and bond energy, E_b at failure are drawn in Figure-4. At the age of 28-days, bond stiffness for 550OPC/SF and 600OPC/SF concrete was determined as 312MPa and 302MPa receptively. On the other hand for 550OPC/MIRHA and 600OPC/MIRHA concrete it was measured as 196MPa and 237MPa respectively.

Although, the MIRHA concrete has shown about 8% lower stiffness than that of the silica fume concrete but it underwent to large amount of relative slip, S_r at failure. The area under f_b-S_r indicates the total bond energy, E_b absorbed by the steel bar. The value of bond energy describes ductility of concrete and/or its bond fracture toughness. 550OPC/MIRHA concrete showed 80% more bond energy as compared to the bond energy calculated of the 550OPC/SF concrete that was obtained as 0.087MPa/mm/mm. Similarly, bond energy for 600OPC/MIRHA concrete was determined as 0.175MPa/mm/mm, which was 74% higher than that obtained for 600OPC/SF concrete.

The ultimate bond strength is defined as the highest point on the f_b-S_r curve, at the age of 3, 7, and 28 days MIRHA concrete mixes showed 8% to 15% higher value than that of the SF concrete. Only, for 550OPC/MIRHA concrete value at 3-days, this was about 5% lower than that of the 550OPC/SF concrete at 3-days.

Figure-5 shows a relationship between ultimate bond strength, f_{bu} and concrete compressive strength, $\sqrt{f_{cu}}$, a well correlated equation was obtained as:

$$f_{bu} = 0.712\sqrt{f_{cu}} \quad (3)$$

This coefficient, 0.712 was obtained higher than the bond coefficient, β that is recommended as 0.40 for normal strength concrete in BS-8110 1997.

4.0 CONCLUSIONS

Based on the results and discussion, following conclusions were drawn from this experimental investigation:

1. In general silica fume has shown about 8% higher compressive strength than that of the MIRHA concrete. All concretes succeeded to achieve 50MPa and above at the age of 3 days and between 80 to 105MPa at 28-days.
2. Silica fume concrete showed 27% to 59% more stiffness than that of the MIRHA concrete. On the other hand, MIRHA concrete exhibited about 8% higher bond energy than that of the silica fume concrete. Higher bond energy means higher ductility value of the MIRHA concrete.
3. On an average of 10% high value of ultimate bond strength of MIRHA concrete was calculated as compared to the ultimate bond strength of silica fume concrete.

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Table-1: Details of concrete mix proportion

Mix Type	OPC kg/m^3	SF kg/m^3	MIRHA kg/m^3	CA kg/m^3	FA kg/m^3	SP kg/m^3
550OPC/SF	550	55	-	670	1120	16.5
600OPC/SF	600	60	-	650	1090	22.5
550OPC/MIRHA	550	-	55	670	1120	18
600OPC/MIRHA	600	-	60	650	1090	24

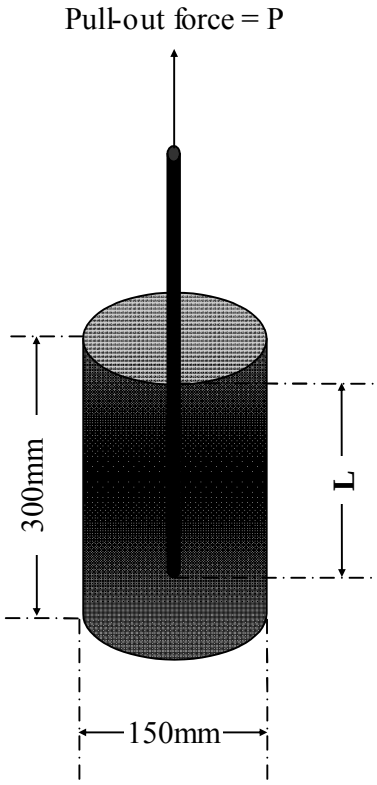

Figure-1: Details of specimen for pull-out test

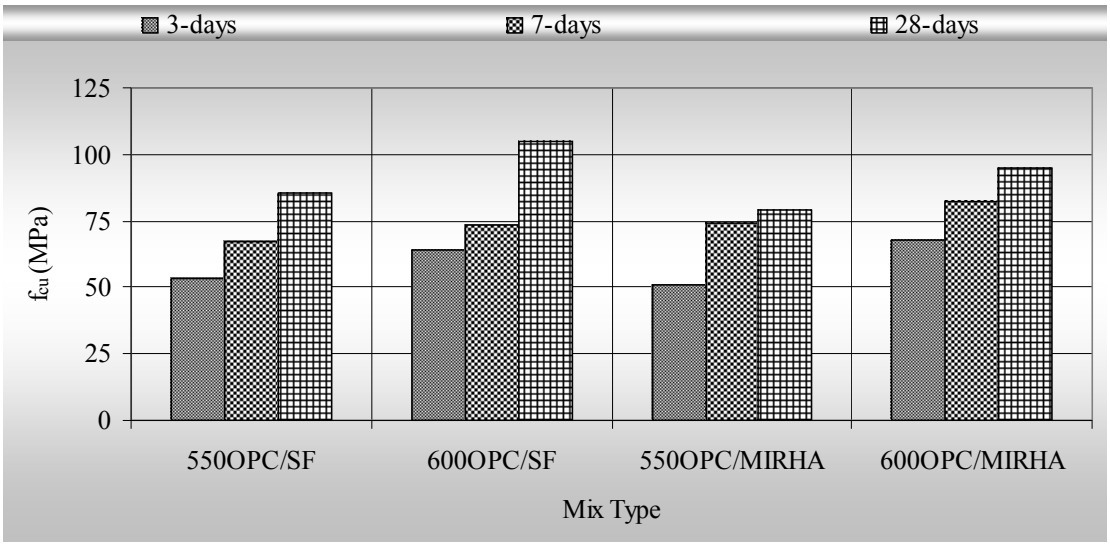

Figure-2: Compressive strength, f_{cu} of concrete mixes determined at different age

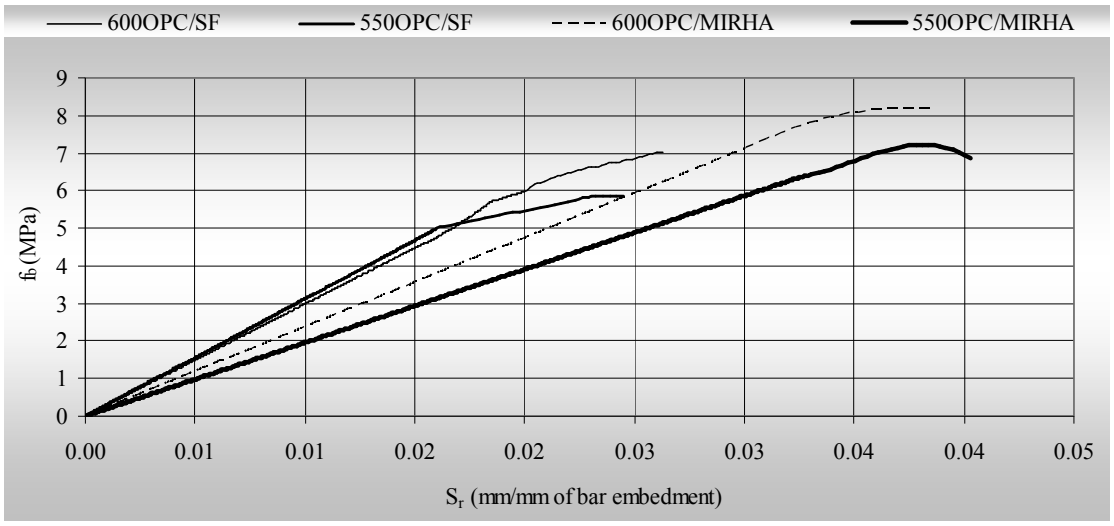

Figure-3: Bond strength, f_b versus relative slip, S_r

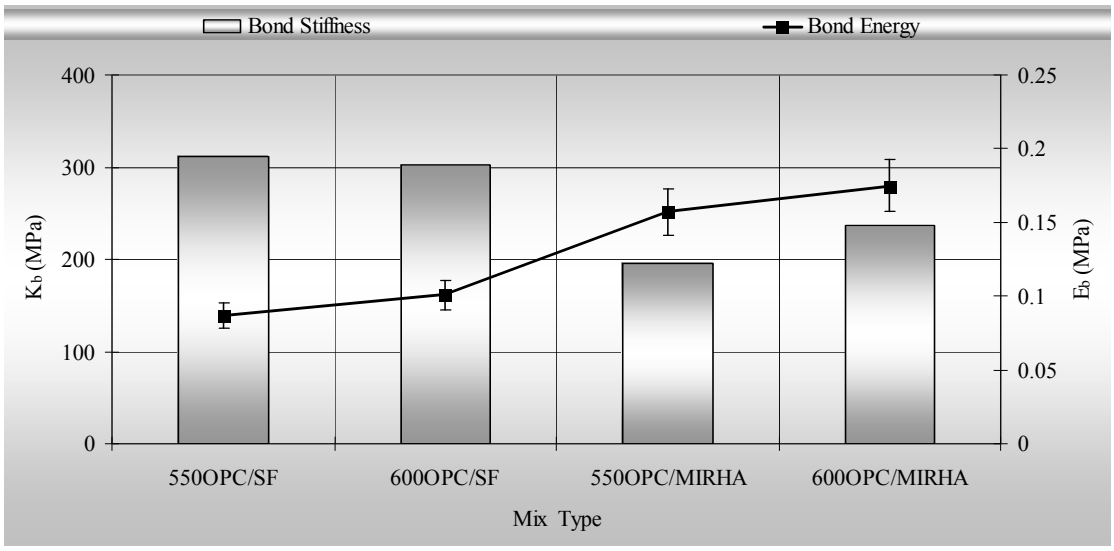

Figure-4: Comparison of bond stiffness, K_b and bond energy, E_b of different concretes

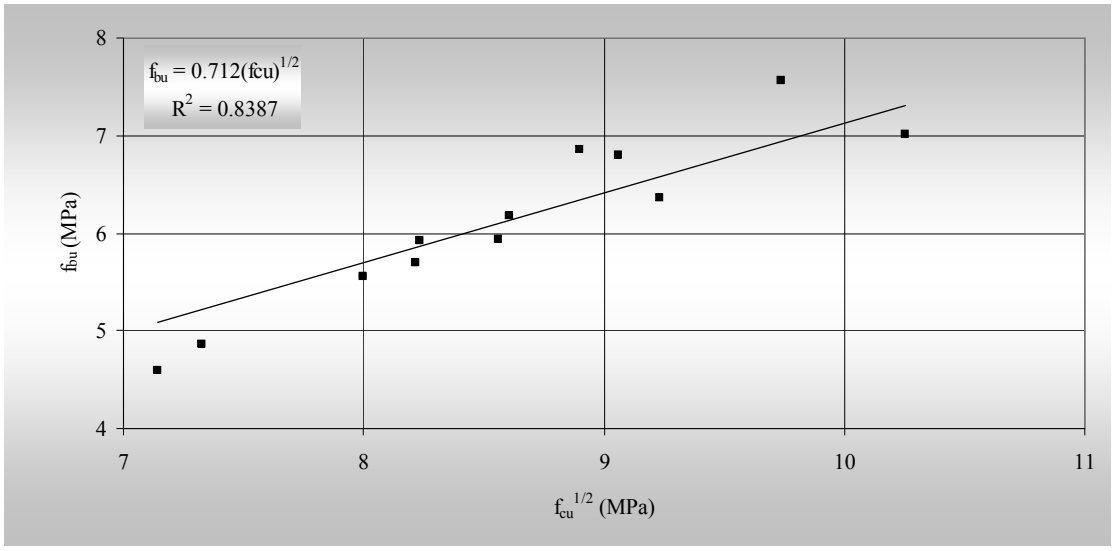

Figure-5: Ultimate bond strength, f_{bu} versus compressive strength, $f_{cu}^{1/2}$