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Factors Affecting Compatibility between (S.B.R) Polymer Repair Materials and Concrete Substrate

Dr. Maan S. Hassan Aseel S. Mansi*
& Haider A. Abdul-Hameed*

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Abstract

In this study, the compatibility of polymer modified repair mortar and substrate concrete was investigated in three stages. First stage includes studying the individual properties of polymer and conventional repair materials, and also two types of concrete, such as compressive strength, split tensile strength, and flexural strength using standard ASTM test procedure. Second stage includes evaluating the bond strength of composite cylinder for different combinations of repair materials and substrate concrete. Third stage includes investigating the compatibility using a composite beam of repair material and substrate concrete under third point loading.

The experimental results show that the compressive strength, split tensile strength and flexural strength is not a crucial factors for the success of concrete repair system. While bond strength tests are provide strong indication about the compatibility. The bond strength of S.B.R polymer material produced by Al-Khaleej Company was not strong enough to be recommended to use for concrete repairing systems.

Keywords: Bond Test; Compatibility; Concrete Repair Materials; Polymer

العوامل ألمؤثره على التوافق بين مواد الإصلاح البوليمرية والجسم الخرساني

الخلاصة

في هذه الدراسة تم التحري عن التوافق بين مواد الإصلاح البوليمريه والجسم الخرساني وعلى ثلاث مراحل. الأولى: التحري عن الصفات الذاتية لكل من مواد الإصـــلاح البوليمريـــه والتقليدية وكذلك لنوعين مختلفين من الجسم الخرساني, مثل مقاومة الانضغاط, مقاومة انفـــلاق الشد، ومقاومة الانثناء. واعتمادا على المواصفة الامريكيه. الثانية: تقييم مقاومة الربط للاسطوانة ألمركبه والمصنوعة من أنواع مختلفة من مواد الإصلاح والخرسانة. ثالثا: التحري عن التوافق باستخدام عتبه مركبه مصنوعة من الخرسانة ومواد الإصلاح وفحصها بطريقة التحميل بنقطتين. تبين نتائج الجزء العملي بان مقاومة الانضغاط, مقاومة انفلاق الشد, ومقاومة الانثناء هي ليست العوامل الحاسمة لنجاح نظام الإصلاح الخرساني. بينما توفر مقاومة الربط مؤشرا قويا عن مدى التوافق. ان مقاومة الربط المتحققة من المادة البوليميرية المتجة من شركة الخليج لم تكن جيـــدة بما يكفي لتكون مفيدة في الاستخدام في نظم الاصلاح الخرسانية.

*Building and Construction Engineering Department, University of Technology/Baghdad

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

1.0 Introduction

With aging of the infrastructure and many concrete structures reaching the end of their design life, maintenance and repair is becoming an increasingly important as a part of the design and construction industry. Complex decisions have to be made in the selection of repair materials and systems in infrastructure rehabilitation. Compatibility of the repair material with the existing substrate is an important consideration if the repair is to withstand all the stresses induced by influences such as volume change and chemical and electrochemical effects [1]. Polymers frequently are used in the formulation of repair mortars because of its particular characteristics (higher adhesion to the substrate, lower shrinkage and permeability they can provide), if properly used [2]. Polymer modified repair materials were developed mainly for their enhanced properties [3]. Ohama et al [4] found that polymer modified mortars showed a decrease in pores in the range 240nm or greater and an increase in the pores of 140nm or less compared to ordinary Portland cement. It was concluded that this refinement of the pore structure resulted in the lower oxygen diffusion coefficients of polymer modified mortars. Al-Zahrani et al [5] mentioned that polymer modified cement repair materials are used to overcome the problems associated with the cement-based repair materials, particularly the need for a longer curing period.

It is very important to study factors affecting compatibility between polymer repair materials and concrete substrate. Several S.B.R (i.e styrene butadiene rubber) polymer products are marketed for the repair of deteriorating concrete structure. Al-Khaleej company trade mark product was chosen to form a specific repair material in this study. The materials properties such as compressive strength, flexural strength, split tensile strength for repair materials and substrate concrete were examined. Bond strengths of the repair materials were investigated to evaluate the compatibility between the polymer modified repair materials and substrate concrete. For this purpose, prisms of composite beam under third point loading as per modified ASTM C78 [6] test procedure were tested.

2.0 Experimental Work

2.1 Materials

The used cement was ordinary Portland cement. It was comply with Iraqi Specification No. 5/1984, and ASTM C 150-99. The specific surface area/Blaine method was $300m^2/kg$. AL-

Ukhaider natural sand of 4.75 mm maximum size was used throughout this work. The sulfate content, bulk density, specific gravity and absorption of the used sand were 0.15%, 1500 kg/m^3, 2.65, and 1.2% respectively. Partially crushed graded gravel of 20mm maximum size was used. The sulfate content, bulk density, specific gravity and absorption of the used gravel were 0.07%, 1630 kg/m^3, 2.63, and 0.63% respectively. Both coarse and fine aggregate are conformed to Iraqi specification No. 45/1984 (zone 2 for fine aggregate). Styrene butadiene rubber (SBR Table 1) emulsion was used throughout this study as a polymer admixture to produce polymer modified mortar.

2.2 Substrate Concrete

Two substrate concrete mixes were used in this study. One mix considered to be low quality substrate, while the other one considered being normal quality substrate. The mix proportion of the concrete is the same, (1:1.6:2.9 by wt.). The deference is only in w/c ratio, which was 0.4 for normal strength concrete 0.6 for low strength. British standard method was adopted to design the normal quality concrete (named as C_{25}), while the low quality concrete (named as C_{15}) was achieved by increase the water cement ratio by about 50% as compared to C_{25}.

2.3 Concrete Repair Materials

Repair material M_c (named as conventional mortar) was a blend of Portland cements with sand. The mortar was proportioned to have a cement-to-sand weight ratio of 1:2 with a water to cement ratio of 0.5. Repair material $M_{S.B.R}$, polymer modified mortar, was prepared by adding S.B.R (15 % of cement by weight), this ratio has been chosen according to previous investigation [7]. The w/c was 0.52 to obtain close flow (100-110%). The cement to sand ratio was the same as in normal mortar. All specimens were cured in water until the age of 28 days, except the $M_{S.B.R}$ specimens cured in air dry which is mandatory for polymer to get hardening [8].

3.0 Evaluation Methods

3.1 Workability

The flow of the repair materials was determined using flow table of mortar as per ASTM C 230-03[9] standard practice. Flow was measured immediately after mixing, within 5 minutes from the time of addition of water into the mix.

3.2 Compressive Strength

The compressive strength of the different repair mortars was determined using 50 mm cube. The compressive strength of concrete was measured on 100mm cube in accordance with BS 1881: part 116[10] by using a standard testing machine. The cubes of the repair materials and substrate concrete were tested in compression at 1 and 28 days age. The average of three cubes was recorded for each testing age.

3.3 Split Tensile Strength

The split tensile strength of the substrate concrete and the repair materials was determined using 100×200mm cylinders as per the ASTM C496-04[11] test procedure. The split tensile strength of the repair materials and substrate concrete were tested at 1 and 28 days age. The average of three specimens was recorded for each testing age.

3.4 Flexural Strength

The flexural strength was determined using the third point loading beam method. The prism sample dimensions were 100×100×400mm, as per ASTM C78-02 [6]. The flexural strength of the substrate concrete and repair materials were tested at 1 and 28 days age.

3.5 Bond Strength

The bond strength of the repair materials was determined using the standard ASTM C882-99 test procedure [12]. In this test procedure, the repair material is bonded to a substrate concrete specimen on a slant elliptical plane inclined at 30° angle from vertical to form a 100×200 mm composite cylinder (see Fig 1). Before the repair material is bonded to the substrate concrete, the slant surface of the substrate concrete specimen is cleaned and dried. The test is performed by determining the compressive load required to fail the composite cylinder and the bond strength is calculated as [Max Load] / [Area of Slant Surface].

3.7 Third Point Loading Composite Prism Test.

In this test method, concrete prisms 400mm in length with a cross-section of 100mm by 100mm were cast as per standard ASTM C 78-02 test procedure. The composite prism for evaluating the compatibility of repair material with substrate concrete was fabricated to the same dimensions as the control prism, with the exception that a wide-mouthed notch 200mm (length) × 100mm (width) × 10mm (thick) was cast into the bottom of the composite prism using a 3-dimensional inset (Fig 2). After de-molding, the prisms were moist cured for 28 days, and then the wide-mouthed notch areas were textured using dry brushing. The rough surface textured substrate specimens were air-dry cured for 7 days before batching the notched area with the repair materials. The composite sections were demolded next day and cured in water for 28 days. After 28 days, the composite sections were tested in third point loading prism test, as per ASTM C78-02 test procedure.

4.0 Results and Analysis.

4.1 Mechanical Properties

Table 2 shows the compressive strength, split tensile strength, and flexure strength of the repair material and substrate concrete. These values are the average of strengths of three samples.

All the strengths found increasing from 1 to 28days. Both repair materials have similar compressive strength at 28 days which is intended to be in equal starting point, while the degree of compatibility enhancement will show the influence of other factors.

The mix proportion of both concrete substrates is the same with the exception of w/c ratio. As a result two types of concrete have been made to simulate the real condition of weak and normal strength substrate concrete, C_{15} and C_{25} (see section 3.2).

The degree of improvement in compressive strength from 1 to 28 days was found to be 75% and 80% for substrate concrete C_{15} and C_{25} respectively. Since the proportion of both C_{15} and C_{25} are the same with the exception of w/c ratio, then this behaviour is related to the differences in w/c ratio. In contrast, test specimens of both repair materials (M_c and $M_{S.B.R}$) exhibited a same gain in compressive strength (i.e. 89.9%) with 28 days. Figure 3 shows the development in strength of the substrate concrete and the two repair materials considered in this study.

It is apparent from observing the data in Figures 3, a, b and c that depending on the specific repair material, significant difference exists between the properties of the repair material and the substrate at any given age. This disparity in strengths can be expected to influence the failure mode and the bond strength determined in the composite cylinder. And also influences the load carrying capacity of the composite beams (this matter will discuss later in section 4.2).

Furthermore, Table 2 and Figure 3 show that differences exist between the properties of the repair materials $M_{S.B.R}$ and M_C were not the same all the time. The degree of enhancement was 1.5%, 3.6%, and 12.7% for compressive, split tensile and flexural strength respectively, at 28 days age. This wide range of differences make difficulties to decide wither these differences is significant or not. So, statistical approach has been used to handle the data, and a T test was adopted to compare the average mean values, Table 3 shows the results.

According to statistics principle [13], a ρ-value greater than the significant level α (i.e 0.05) signifies that no significant difference exists between the measured two values. For instance, ρ-value = 0.035 which is less than 0.05 signifies the difference in compressive strength values between M_C =19.6 MPa and $M_{S.B.R}$ =19.9 MPa. Hence, the conclusion that there is an enhancement in compression strength at 28 days age, associated with using S.B.R is considered acceptable. Similarly, since the ρ-values 0.049 and 0.001 are less than 0.05, and then the conclusion that there is an enhancement in split tensile and flexural strength is considered acceptable too.

Pattnaik [14] found three different modes of failures. They are (as shown in figure 4): slant surface failure indicating of the weak bond between the repair and substrate materials. While materials failure, (either in substrate concrete or mortar), indicating weaker materials strength than the bond strength at the interface.

The failure mode observed in this study for composite cylinder was slant surface for $M_{S.B.R}$ specimens. In contrast, mixed mode failure (i.e. slant surface and material failure) were observed in M_c composite cylinder specimens test. Figures 5, and 6 show different types of failure mode.

4.2 Compatibility Results

It is well established that a prism of higher total depth value deflects less in the flexure test compared to a prism of lower depth value under the same loading. In the composite prism, if the repair system is failed in bond, and there is a de-bonding between the batched notched area and the substrate, the total depth will be reduced, and the load deflection curve should have lesser slop than the slop of the load deflection curve of compatible composite prism (i.e without de-bonding) as shown in Figure 7. Otherwise, the load will transfer to repair material, and the composed prism consider compatible.

Table 4 shows the bond strength, and third point strength of composite beams. These values are the average of strengths of three samples.

Due to the higher split tensile and flexural strengths of $M_{S.B.R}$ than M_c, it is expected that the third points test results of $M_{S.B.R}$ will be more than M_c results too. In contrast, Table 4 expresses different trend. The flexural strengths of prism composed of substrate C_{15} repaired by $M_{S.B.R}$ was 1.39 MPa which is less than 1.98 MPa for the same substrate repaired by M_C. On the same direction, flexural strengths of prism composed of substrate C_{25} repaired by $M_{S.B.R}$ was 2.64 MPa which is less than 3.28 MPa for the same substrate repaired by M_C. A probable explanation of such behavior is that the degree of compatibility of $M_{S.B.R}$ with substrate concrete was less than M_C, despite of its better strengths. Bond strength results shown in Table 4 indicates that the bond strength of M_c with both substrates concrete were 7.43 and 9.1 MPa which is more than 6.44

and 4.5 MPa for $M_{S.B.R}$ respectively, and it is again support such explanation. Images shown in Figure 8 and 9 indicate two types of failure mode. Figure 8 detect that fracture surface has shifted away from the patched area, and no de-bonding has been observed for prism repaired by M_C. while Figure 9 detects that complete de-bonding has been achieved between substrate and $M_{S.B.R}$, and fracture surface has been occurred near mid span. Moreover, all the bond results of M_C shown in table 4 were better than $M_{S,B.R}$ results while the main aim of using S.B.R products with repair mixes is to improve such bond property.

The authors believe that this weak behavior of bond strength of S.B.R specimens are related to the trade mark of the chosen type of S.B.R product (i.e Produce by Al-Khaleej Company trade mark), and other products of S.B.R available in the local markets, need to be investigated.

5.0 Conclusions

Based on the results from the experimental program it can be concluded the following:

1. Using S.B.R will improve the compressive split and flexural strength of $M_{S.B.R}$ repair material compared with conventional mortar M_C.
2. The compressive, split tensile and flexural strengths are not the crucial factors in the success of repairing systems. It is the bond between repair and substrate concrete which is greatly influence the compatibility of concrete repairing systems, and therefore determine its successful use.
3. Since the bond strength of $M_{S.B.R}$ repair material produced by Al-Khaleej Company, were less than that of M_C, it is not recommended to use this type of S.B.R for concrete repairing purposes.

The authors would like to mention that the present study represent the 1st part of two parts research work. While the 2nd one (currently under publication) concerns about using of pozzolanic repair materials with substrate concrete, and the results is seem to be agreed.

Further investigations need to be done to recognize the effect of surface texture and roughness on bond strength. It is recommended also to investigate other types of S.B.R products available in the local markets.

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Table (1): Properties of Styrene Butadiene Rubber (S.B.R) Produce by Al-Khaleej Company*

Physical state	Milky white liquid
Total solids (by weight of polymer)	48%
Specific gravity	1.01
PH	10.5

*Properties obtained from product catalogue

Table (2): Strength Results of Repair Materials and Substrate Concrete.

Materials type	Compressive strength (MPa)		Split tensile strength (MPa)		Flexural strength (MPa)	
	1-day	28-day	1-day	28-day	1-day	28-day
Substrate concrete 0.6 C_{15}	4.3	17.6	0.39	1.44	0.7	4.12
Substrate concrete 0.4 C_{25}	5.9	30	0.53	2.3	1.32	5.81
Conventional repair materials M_c	2	19.6	0.18	1.38	1.47	3.45
Polymer modified repair materials $M_{S.B.R}$	1.7	19.9	0.48	1.43	1.44	3.89

Table (3): Statistical T-test Results for Average Strength Comparison

	Compression strength 28 days (MPa)	Split tensile strength 28 days (MPa)	Flexural strength 28 days (MPa)
M_C	19.6	1.38	3.45
$M_{S.B.R}$	19.9	1.43	3.89
T-value	5.196	4.33	38.1
ρ-value	0.035	0.049	0.001
α-value (Significant level)	0.05		

Table (4) Compatibility Test Results of Repair Materials and Substrate Concrete at 28 Days Age

Materials type	Bond strength- (MPa)		Third point composite prism (Flexural strength)-(MPa)	
	M_c	$M_{S.B.R}$	M_c	$M_{S.B.R}$
Substrate concrete 0.6 C_{15}	7.43	6.44	1.98	1.39
Substrate concrete 0.4 C_{25}	9.1	4.5	3.28	2.64

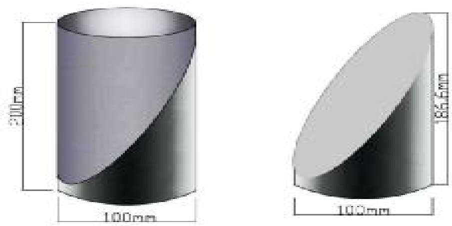


Figure (1) Substrate and Composite Section for Slant Shear Bond-Strength Test.

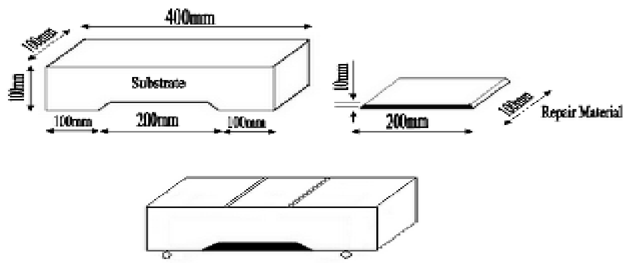
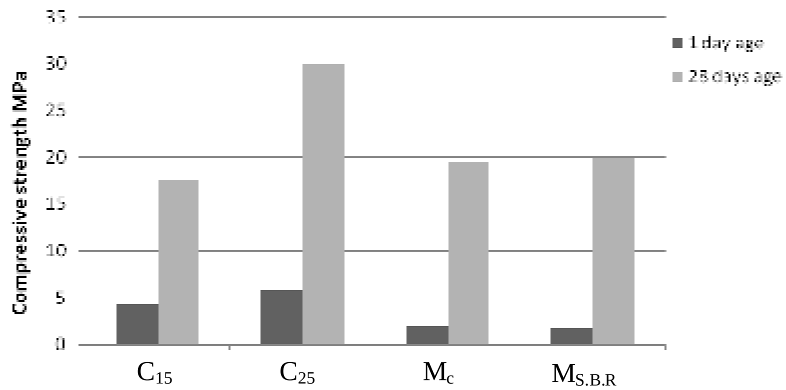
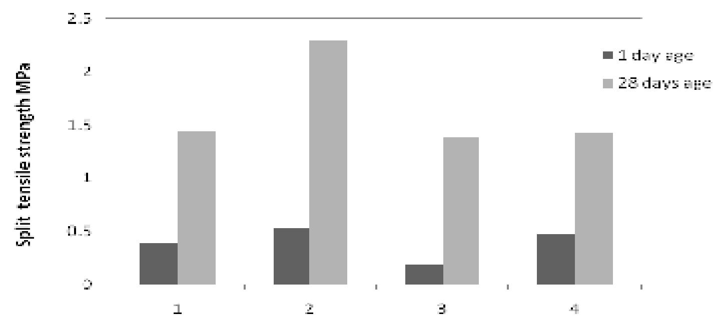


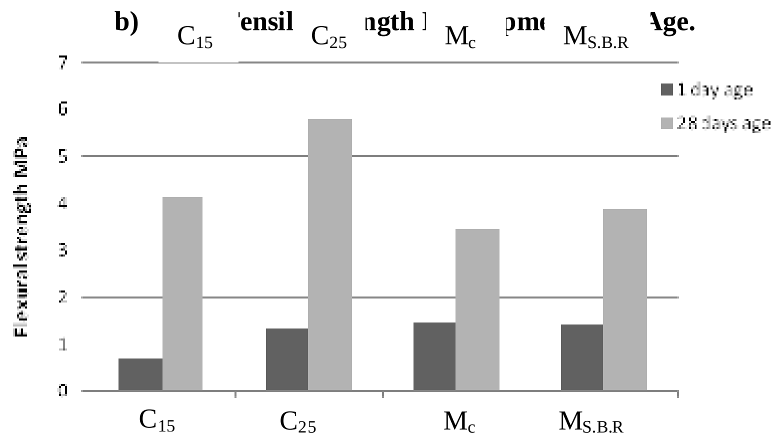
Figure (2) Third Point Loading Composite Beam.



a) Compressive Strength Development with Age.

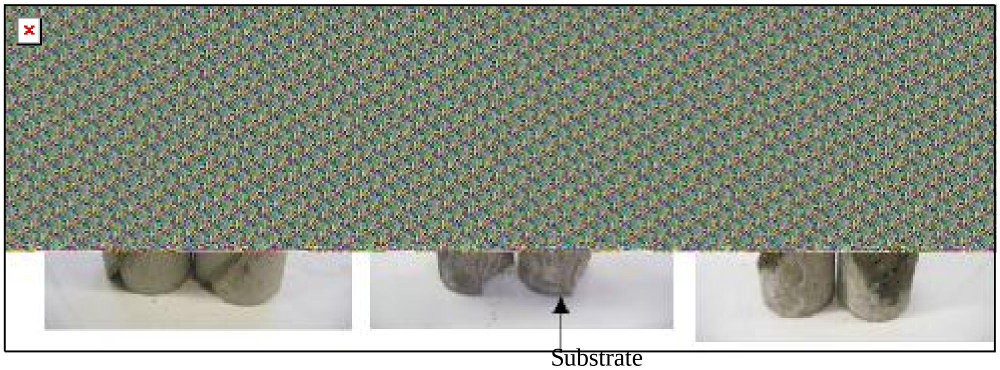


b) 'ensil ngth] pm Age.



c) Flexural Strength Development with Age

Figure (3) Compressive, Split Tensile and Flexural Strengths Development of Repair Materials and Substrate Concrete.



(a) Interface (b)Substrate failure (c) Repair material

Figure (4) Failures of the Composite Slant Sections [14].

Figure (5) Mixed Failure Mode of M_c with C_{15} Composite Cylinder Specimens at 28 Days Age.

Figure (6) Slant Shear Failure Mode of $M_{S.B.R}$ with C_{25} Composite Cylinder Specimens at 28 Days Age.

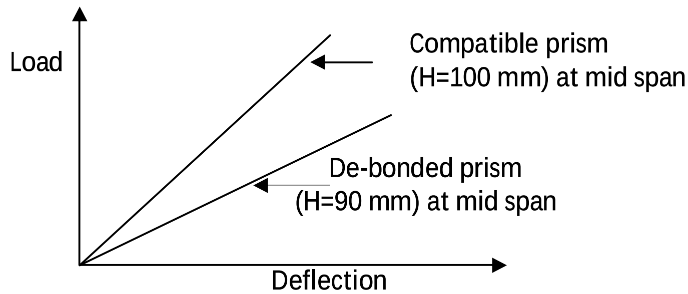


Figure (7) Typical Load Deflection Relationship of a Composed Prism.

Figure (8) Prism Composed of C_{15} Repaired by M_C, 28 Days Age.

Figure (9) Prism Composed of C_{25} Repaired by $M_{S.B.R}$, 28 Days Age.