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Bond Strength Assessment for Different Types of Repair Materials

Aseel S. Mansi*

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Abstract

The main objective of this work is to evaluate the bond strength for different types of repair materials. Three test methods; slant shear, splitting prism and Bi-Surface shear test with conventional and two polymer modified repair mortars were used, The conventional mortar (M_C), polymer modified mortar (M_{SBR}) was prepared by admixing SBR 15% of cement weight, polymer modified and fiber reinforced repair mortar named commercially Cempatch S (M_{CS}) was prepared by mix Cempatch S with a water ratio of 0.2.

The results show that the use of SBR and Cempatch S improves the bond strength of repair mortar compared with conventional repair mortar but the percentage increased with Cempatch S was greater than SBR. The percentage increase in bond strength for concrete substrate repaired with Mcs (CMcs) were 52.67, 174.8, and 46.7% for Slant Shear, Splitting Prism and Bi-Surface shear test respectively relative to the corresponding repaired with conventional mortar $M_C(CM_C)$; while, the corresponding percentages increase for concrete substrate repaired with M_{SBR} (CM_{SBR}) was 45.13, 129 and 30%. It is found that the bond strengths obtained from some tests was up to an average of four times larger than those obtained from others.

Keywords: Polymer; Concrete repair materials; Bond strength, Cempatch S.

تقييم مقاومة الربط لأنواع مختلفة من مواد الإصلاح

الخلاصة:-

في هذه الدراسة تم التحري عن تقييم مقاومة الربط لأنواع مختلفة من مواد الإصلاح. تم استخدام ثلاثة طرق لفحص مقاومة الربط, طرق الفحص المستخدمة هي فحص القص المائل, فحص انشطار الموشور وفحص القص الثنائي السطحي لكل من مواد الإصلاح البوليمرية والتقليدية. مواد الإصلاح المستخدمة هي المونة التقليدية والمونة المعدلة ببوليمير SBR تم تحضيرها باضافة مادة SBR بنسبة 15% والمونة المعدلة ببوليمير SBR والمسلحة بالالياف المسماة تجاريا Cempatch S تم تحضيرها بخلط مادة Cempatch S مع الماء بنسبة 0,2 .

أظهرت النتائج بان استخدام بوليمير SBR واستخدام مادة Cempatch S قد حسن مقاومة الربط لمونة الإصلاح مقارنة مع مونة السمنت العادية ولكن نسبة الزيادة باستخدام مادة Cempatch S كانت أعلى مقارنة مع مادة SBR, حيث كانت نسبة الزيادة في مقاومة الربط للجسم الخرساني المصلح بمادة Cempatch S هي 52,67 و 174,8 و 46,7 % لفحص القص المائل, فحص انشطار الموشور وفحص القص الثنائي السطحي على التوالي, بينما كانت النسبة الزيادة للجسم الخرساني المصلح بمادة SBR هي 45,13 و 129 و 30 %. وتبين أن مقاومة الربط لبعض أنواع الفحوص تبلغ معدل يصل إلى أربعة أضعاف تلك المستحصلة من فحوصات أخرى.

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

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1-Introduction

A wide variety of patch repair materials are now available to the industries, which can be classified into three primary groups: cementitious mortars, polymer-modified cementitious mortars, and resinous mortars [1]. Table 1 illustrates how these groups can be further subdivided.

It is essential that the engineer should have a thorough knowledge of the mechanical and physical characteristics of the available products and the existing substrate before a suitable repair material is chosen [1].

With the rapid increase in the decay of infrastructure worldwide, there is a great deal of interest in bond between existing concrete substrate and repair materials. The measured bond strength is highly dependent on the test method used, size and geometry of specimen and the state of stress on the contact surface. It is noted that certain standard tests have been developed for specific applications and state of stress. For example, the slant shear is used to evaluate the bond strength of resinous materials, epoxy bonding agents, and latex bonding agents under a combined state of stress of compression and shear [2,3,4].

While bond tests have been developed for specific applications, there is no consensus among practitioners for evaluating the bond strength under a state of shear stress that is commonly encountered in buildings [2].

Delatte et al [5]. Presented methods for estimating the bond development between concrete overlay and its underlying substrate at early ages on the basis of concrete maturity. Tension bond strength and shear bond strength were reported to be a function of mixture proportioning and curing temperature. Bond between concrete and overlays has also been studied by Petersen et al. [6].

This study compares the bond strength measured by three different test methods were slant shear, splitting prism and Bi-Surface shear test and two different categories of repair materials were conventional and polymer repair materials .

2-Experimental work

2-1 Materials

2-1-1 Cement

The used cement was ordinary Portland cement Type I. The cement was tested and checked according to IOS 5:1984[7]. Table (2) shows the chemical properties of this cement; and the physical properties are shown in Table (3).

2-1-2 Fine Aggregate

AL-Ukhaider natural sand of 4.75 mm maximum size was used throughout this work. Table(4) shows the grading of fine aggregate. Results showed that the fine aggregate grading and sulfate content were within the requirements of the Iraqi specification No.45/1984 [8].
Table (5) illustrates the specific gravity, sulfate content and absorption of fine aggregate.

2-1-3 Coarse Aggregate

Crushed gravel with maximum size of 20 mm from Al-Niba'ee region was used .The grading of coarse aggregate, given in Table (6), conforms to the Iraqi specification No.45/1984[8]. Table (7) shows the physical properties of the coarse aggregate.

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2-1-4 Water

Tap water was used for both mixing and curing of concrete.

2-1-5 Polymers

1- Styrene Butadiene Rubber (SBR)

Swiss Chem company trade mark product was used throughout this study as a polymer admixture to produce polymer modified mortar; table 8 shows properties of SBR.

2- Cempatch S

Cempatch S is a single component polymer modified and fiber reinforced repair mortar. Cempatch S is a blend of dry powders, selected aggregates and fibers which when mixed with water produces a thixotropic mortar suitable for vertical and overhead application.

2-2 Mixes

2-2-1 Substrate Concrete

The same mix design was used for the concrete in substrate portion of all specimens. The mix proportions were 1:2:4 by weight with w/c= 0.4 to obtain compressive strength of 31 MPa at 28 days, a minimum Portland cement of 400 kg/m^3 was used.

2-2-2 Concrete Repair Materials

Three mixes of repair materials were used and one continuous bond composed of the substrate concrete material to allow comparison of the results of repaired specimens with monolithic sample. One of the repair materials named as conventional mortar (M_c) 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 in order to obtain a flow of (100 ─ 110) %. The second repair material, polymer modified mortar (M_{SBR}) prepared by admixing SBR 15 % of cement by weight, this ratio has been chosen according to previous investigation [2]. The water –cement ratio used was 0.45 to match the required flow (100 ─ 110)%. The cement to sand ratio was the same as in conventional mortar. The third repair material, polymer modified and fiber reinforced repair mortar (Mcs) prepared by mix Cempatch S with a water ratio of 0.2 in order to match the required workability (100-110) %. Mixing procedures were as close as possible to the standards. All the specimens were cured in water until the age of 28 days, except the M_{SBR} specimens cured in air dry which is mandatory for polymer to get hardening [9].

2-3 Test Program

The experimental program includes preparing 48 specimens which were tested in splitting prism, and slant shear. Besides these tests, a newly developed direct shear method on Bi-surface shear test was examined [2]. The sizes of all specimens are shown in Fig.1. The splitting prism specimens were 150×150×150mm cubes. In the Bi-surface shear method, the repair material constitutes one third of the specimen. In other worlds, using 150mm cubes forms, prisms with a base size of 100×150mm and height of 150mm are cast as old or substrate concrete(Fig.2a); the repair materials are cast in prisms with a base of 150×50mm and a height of 150mm and are bonded to the concrete substrate(Fig.2b). The loading on these specimens causes a shear failure. This failure is more common in practice compared to a shear-Compression failure that is produced in slant shear tests.

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2-4 Experimental Tests

2-4-1 Flow of Repair Material

The flow of the repair materials was carried out according to ASTM C230[10]. By using the flow table of mortar flow was measured immediately after mixing, within 5 minutes from the time of addition of water to the mix.

2-4-2 Slump for Concrete Mixes

Slump test is a suitable test to determine the workability for concrete mix. The procedure was conducted in accordance with ASTM C143-89a [11]. The water-cement ratio for all mixes was adjusted to maintain equal workability of 70±5mm slump.

2-4-3 Compressive Strength

The compressive strength of the different repair mortars was determined from 50-mm cube, according to ASTM C109 [12]. The compressive strengths of substrate concrete were determined from 100-mm cube, according to B.S.1881: part 116[13]. The specimens of the repair materials and substrate concrete were tested in compression at 28 days, the average compressive strength of three cubes were recorded.

2-4-4 Bond Strength

Three different bond strength test methods (splitting test, slant shear test and Bi-surface shear test) was carried out in this investigation each test represent one category of tests measure the bond between concrete substrate and repair material.

The bond tests between concrete substrate and repair material can be divided into several categories. The first category of tests measures the bond under tension stress; the main test under this category is the Splitting test (Fig.1a) [14]. In the splitting test, a prism with square cross-section is placed under longitudinal compressive loading (Fig.1a). Tension stresses cause failure in a plane passing through upper and lower axes of loading and split the specimen into two halves.

The second category of tests measures the bond under shear stresses and is called direct shear methods. Several tests fall under this category, including L-Shaped, monosurface shear, etc. [2]. In most cases, the bond surface for a direct shear test is actually subjected to shear stress and small bending stress. When a steel plate is used to transmit the shear force a long the bond line, some stress concentration at the edge of the bonding plane is induced. Smaller stress concentration leads to smaller scatter in test results [15]. In this paper Bi-surface shear was used which is a new direct shear method referred to the above test [2]. Typical test specimen dimensions and direction of load are shown in (Fig.1b).

The third category measures the bond strength under a state of stress that combines shear and compression. Slant shear test ASTM C882 [3] fall under this category. In this test, the repair material is bonded to a substrate concrete specimen on a slant elliptical plane inclined at 30° angle from vertical to form 100×200mm composite cylinder (see fig.1c). During loading, the interface surface is under compression and shear stresses. The slant shear test has become the most widely accepted test, and has been adopted by a number of international codes as attest for evaluating the bond of resinous repair materials to concrete substrates [16].

2-5 Preparation of Specimens

The concrete and mortar were manufactured in the laboratory by

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using pan mixer with capacity of 0.1 kg/m^3 and were placed in lubricated steel moulds. Wood pieces were used to form the block-outs (Fig .2a). The specimens were removed from the moulds after 24 hours of casting; they were cleaned from any extra dust or particles.

It was observed that the influence of surface roughness is more pronounced when the repair materials have low adhesion properties [2]. Since the polymer-modified repair materials have higher adhesion properties, therefore the repairing surfaces were not roughened.

The concrete specimens were kept in water until the age of 28 days, and then they were air dried for 7 days. The contact surface of the specimens was cleaned using a wire brush after that the repair material was placed. The composite sections were demolded after 24 hours and cured in water until the age of 28 days except the specimens which repaired with polymer modified mortar, and then the composite sections were tested.

3- Results and Analysis

The bond strength for all methods, except for the splitting, was calculated by dividing the maximum load at failure by the bond area; that is, for the slant shear test, the bond strength is calculated as [Max Load]/[Area of slant shear]. The splitting tensile strength was calculated by the following equation:-

$\sigma = 2P/\pi A$ (1)

Where δ=splitting tensile strength, MPa; P=applied load,N; and A=area of bond plane, mm^2[2].

In order to compare the results of repaired specimens with a monolithic sample (continuous samples) which represent the substrate concrete without any represent the repairing. These specimens were cast in a single stage, so there is no predefined interface plane. An equivalent bond strength for these specimens was calculated by dividing the applied force by the corresponding non continuous bond area values, e.g., sloping area in the case of slant shear test[2].

The failure mode observed in this study for composite section was failed in bond for CM_{SBR} and CM_C specimens in splitting prism and Bi-surface shear specimens while in CMcs specimens were failed by bond failure in Bi-Surface shear in other hand the failure mode in splitting prism test was bond failure and we notice some of the substrate material broken and adhesive with repair material as shown in Fig.(3) which point to the high bond of the Cempatch S. In contrast, mixed mode failure (i.e. slant surface and material failure) were observed in CM_C specimens for slant shear test while material failure was observed as cracks in CM_{SBR} and CMcs specimens expanded from repair material to the substrate.

Table (9) shows the test results, including the **$f`_c$** of repair mortar mixes and substrate concrete, σ = the mean bond strength (Mpa). It can be noticed that the use of the both types of polymer modified materials improves the bond strength values compared with conventional mortar for all bond strength tests methods, also, for all these tests the use of Cempatch S improves the bond strength higher than SBR. The percentage increase in bond strength for CMcs were 52.67, 174.8, and 46.7% for Slant Shear, Splitting Prism and Bi-Surface shear test respectively

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relative to the corresponding conventional mortar. While the corresponding percentages increase in bond strength for CM_{SBR} was 45.13, 129 and 30%. This behaviour might be due to the property of Cempatch S to controlled shrinkage.

Table (9) and Fig.(4) show the results of the bond strength obtained from different test methods. It can be seen that shear test give the highest bond strength for all types of repair materials. This can be attributed to the high compressive stresses that exist in slant shear test, These compressive stresses produce higher interlock and friction forces that increase the shear failure load[1]. Also table (9) and Fig.(4) also show that continuous specimens had highest bond strength from splitting-prism and Bi-Surface shear tests than those for the CM_{SBR} specimens, while the bond strength for CM_{SBR} and CMcs specimens obtained from slant shear test was higher than those for the continuous specimens. In the other word it is noted for that the continuous specimens had the highest bond strength from all different tests than those for the CM_C specimens.

From table (9) and fig (4) it can be observed that bond strengths values from slant shear and Bi-Surface shear test higher than those from splitting prism test. Therefore, when the interface is under a state of tension stress, results from slant shear or Bi-Surface shear should not used. Conversely, reliance on splitting bond strengths for applications where the interface is subjected to shear or shear and compression can under estimate the true bond strength. The improvements in bond strengths values caused by the addition of SBR and use of Cempatch S were higher for those tests that cause shear (i.e. , slant shear, Bi-Surface shear test). This demonstrates that adding SBR and use of Cempatch S are more effective under shear stresses than tension stresses.

The ratios of bond strength of repaired specimens to that for the continuous samples are shown in Fig.(5) This comparison is important because in spite of the large differences that exist among the absolute measured bond strengths Fig.(4), the value of each test can only be judged in terms of its ability to predict the strength of a continuous sample tested under the same conditions. A ratio of one, represent a repair material whose application dose not introduce a new weak link in the structure. Regardless of the materials used, the bond strength decreases for various test in the following order: slant shear, Bi-Surface shear, and splitting as shown in Fig.(5).

Considering conventional mortar materials, tests that fail under tension (i.e., splitting-prism) measured a value that was 32% of the continuous sample while the other two tests (Bi-Surface and slant shear) give much higher values (66-74% with an average of 70%). This clearly indicates that when conventional mortar materials are used for repair, the most conservative results are obtained when splitting test is employed. Furthermore, it is evident that the bond strength of conventional mortar materials under tension is less than 40% of the continuous samples. Therefore in such applications, the use of polymer-modified materials results in bond strengths that more closely represent a monolithic structure. Although the same trend exists for modified polymer-modified materials,

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the differences are not quite as large; 75% for splitting, versus 87-114% with an average of 100% for Bi-Surface and slant shear.

4-Conclusions

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

1. Using polymer-modified mortars will improve the bond strength of repair materials compared with conventional mortar for all bond strength test methods. The percentage increase in bond strength for CMcs were 52.67, 174.8, and 46.7% for Slant Shear, Splitting Prism and Bi-Surface shear test respectively relative to the corresponding conventional mortar. While the corresponding percentages increase in bond strength for CM_{SBR} was 45.13, 129 and 30%.
2. The use of Cempatch S improves the bond strength higher than SBR, and it is recommended to use it in repair materials.
3. The bond strengths from some tests up to an average of four times larger than those obtained from others. Therefore it can be concluded that it is very important to select the bond strength test which represent the state of stress subjected on the structure in the field.
4. The measured bond strength decreases for various tests in the following order: slant shear, Bi-Surface shear, and splitting-prism shear test.
5. For the polymer-modified materials studied, splitting test product bond strengths that is 75% of the bond strength of a monolithic sample, while Bi-Surface and slant shear tests produce values that are 100% of the continuous samples.

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Table (1) Types of repair materials[1]

Cementitious materials	Polymer-Modified Cementitious materials	Resinous materials
Ordinary Portland Cement (OPC)	Styrene Butadiene Rubber modified	Epoxy mortar
High Alumina cement (HAC)	Vinyl Acetate modified	Polyester mortar Acrylic mortar

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Table (2) Percentage oxide composition and main compounds of the cement used throughout this work.

Oxide composition	Abbreviation	Percentage by weight	Limit of Iraqi Specification NO.5/1984
Lime	CaO	63.23	–
Silica	SiO2	20.12	–
Alumina	Al2O3	5.54	–
Iron Oxide	Fe2O3	3.41	–
Sulphate	SO3	1.61	≤ 2.8 %
Magnesia	MgO	4.75	≤ 5.0 %
Potash	K2O	0.36	–
Soda	Na2O	0.2	–
Loss on ignition	L. O. I.	0.73	≤ 4.0 %
Insoluble residue	I. R.	1.24	≤ 1.5 %
Main Compounds (Bogue's equations)			
Tricalcium Silicate	C3S	57.74	–
Dicalcium Silicate	C2S	14..21	–
Tricalcium Aluminate	C3A	8.92	–
Tetracalcium Alumino- Ferrite	C4AF	10.34	–

Table(3) physical properties of cement.

Physical properties	Test results	Limits of Iraqi Specification NO.5/1984
Specific surface area (Blaine method) (m^2/kg)	325	≥ 230
Soundness (Le-chatelier method) (mm)	0.66	<10
Setting time (Vicat's method) Initial setting (hrs:min.) Final setting (hrs:min.)	2:40 4:25	≥ 45 min. ≤ 10 hrs
Compressive strength (MPa) 3 days 7 days	16.90 28.70	≥ 15 ≥ 23

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Table (4) Grading of fine aggregate.

Sieve size (mm)	Cumulative passing (%)	Limits of the Iraqi specificationNo.45/1984,zone 3
10	100	100
4.75	92.6	90-100
2.36	87.3	85-100
1.18	77.9	75-100
0.60	63.1	60-79
0.30	28.5	12-40
0.15	7.4	0-10
Fineness modulus =2.43		

Table (5) Physical properties of fine aggregate.

Physical properties	Test results	Limits of the Iraqi specificationNo.45/1984
Specific gravity	2.65	–
Sulfate content %	0.2	≤ 0.5 %
Absorption %	0.70	–

Table (6) Grading of coarse aggregate.

Sieve size (mm)	Cumulative passing (%)	Limitations of the Iraqi specificationNo.45/1984[8]
20.0	100	95-100
14.0	-	-
10.0	59	30–60
5.00	1	0–10
2.36	-	-

Table (7) Physical properties of coarse aggregate

Physical properties	Test result	Limit of Iraqi specification No. 45/1984[8]
Specific gravity	2.63	-
Sulfate content %	0.06	≤ 0.1 %
Absorption %	0.63	-

Table (8) Properties of Styrene butadiene rubber (SBR)*

Appearance	Liquid
Specific gravity	1.04
Chloride content	Nil
Solid by volume	29%

*Properties obtained from product catalogue

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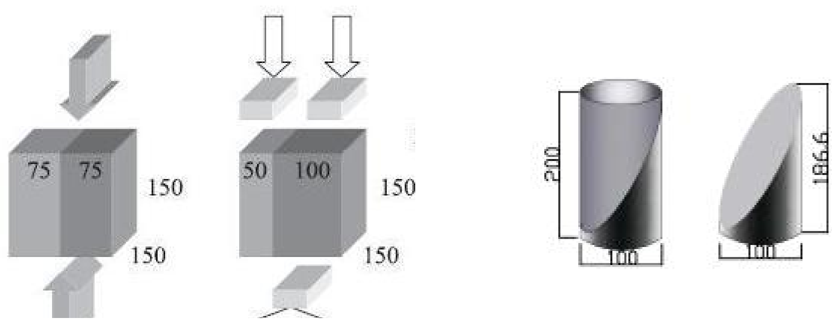
Table (9) Experimental test results

Specimen symbol	f`$_c$ of substrate concrete (Mpa)	f`$_c$ of repair material (Mpa)	Bond strength test		
			Splitting prism	Bi-surface shear	Slant shear
			σ (Mpa)	σ (Mpa)	σ (Mpa)
Concrete substrate repaired with M_C(CM_C)	31	36	1.31	3.0	10.48
Concrete substrate repaired with M_{SBR}(CM_{SBR})	31	22	3.0	3.9	15.21
Concrete substrate repaired with M_{cs}(CM_{cs})	31	56	3.6	4.4	16.0
Continuous (Cont)	31	-	3.97	4.5	14.0



a) Splitting Prism **(Bi-Surface)** **c) Slant Shear**

Figure (1) Dimensions of tested specimens in millimeters

a) Wood to form block-out b) Ready to place repair material

Figure (2) Fabrication of cube samples for Bi-surface shear test

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Figure (3) Failure of the substrate in splitting prism test

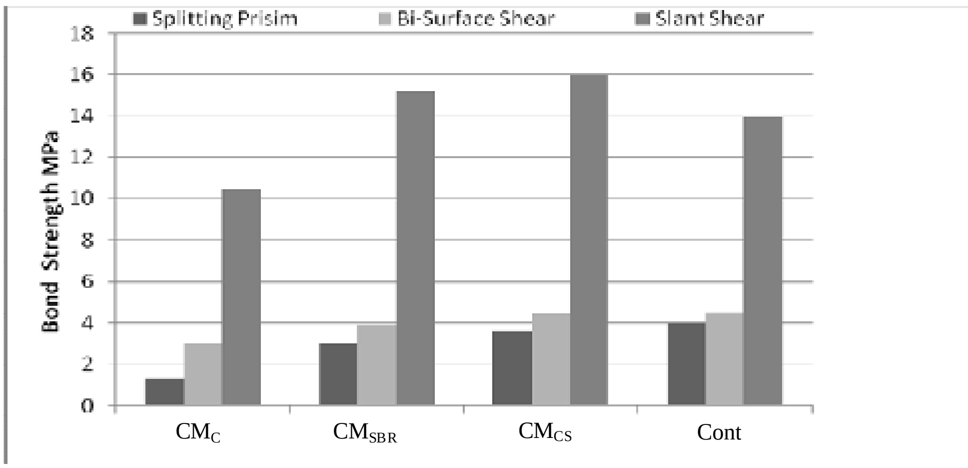

Figure (4) Effect of different bond tests and different types of repair materials on the bond strengths value

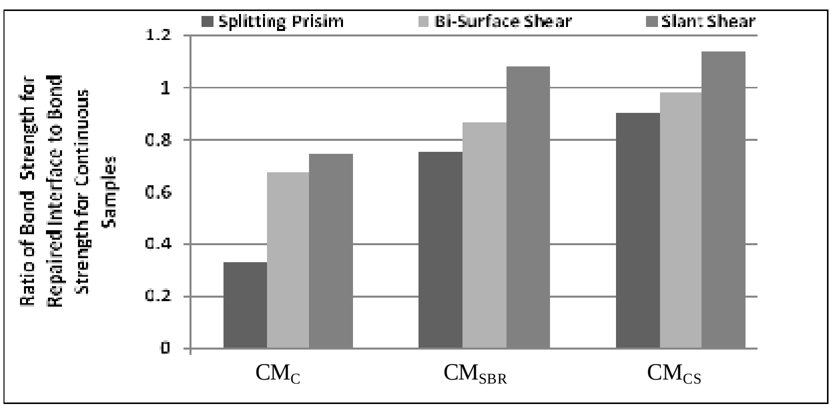

Figure (5) Effect of type of repair material and bond test on the ratio of bond strength of repaired interfaces to that for continuous specimens

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