OPEN ACCESS

International
Journal
Of Modern Engineering Research (IJMER)

Repairing of Concrete by Using Polymer-Mortar Composites

Yaser M. Abdulateef [1], Besma M. Fahad[2], Khalid M. Eweed[3]
[1]MSC. Student, Department of Material Engineering, College of Engineering, University of Al-Mustansiriya, Iraq
[2,3]Asst. Prof. Department of Material Engineering, College of Engineering, University of Al-Mustansiriya, Iraq

Abstract: *Replacement of concrete buildings, bridges, roadways and other structures is becoming more and more expensive as costs of materials and labor continue their upward spiral. Polymer-modified or polymer cement mortar (PCM) and concrete (PCC) are a category of concrete-polymer composites which are made from cement mortar or concrete with polymers, The main application of polymer cements is in concrete repair. In this research two sets of mixtures were prepared that consist of mortar and polymer to fabricate the polymer-cement composite. The first set include mortar with ratio (1:1) (cement-sand) without water, while the other set include mortar with ratio (1:2) (cement-sand) without water. The polymer was Quickmast105 epoxy which is added to the mortar after mixing the resin with the hardener in proportion of (1:3). Each set was consist of different percentage of polymer (50:50, 40:60 and 30:70). Tests were conducted, including compression, flexural and bonding strength, were several results obtained including, the highest compressive strength was about 102.889MPa and the highest value of flexural strength was about 57.648MPa for (1:1), the polymer-mortar with 40:60 ratio showed a higher bonding compressive strength. Proportionality between the cement and sand and also between the polymer and mortar plays a major role in adhesion and strength are considered key factors in the bonding and portability to repairs.*

Key Words: *Polymer, mortar, composite, polymer – cement, repairing.*

I. Introduction

Concrete today is an indispensable part of the fabric of modern society, used for everything from mundane road pavements and high rise building structures. Despite its long history of use, our understanding of the material has only really developed in very recent times, particularly with respect to its durability. There was common view that concrete is a durable as well as a maintenance-free constructional material. In recent years this concept has been changed. Many investigations have shown that concrete does not perform as well as it was expected due to the effect of many factors which contribute to or cause the deterioration of concrete structures and that what make it necessary of repairing concrete. [1]

In the last 30 years the construction industry branch having to do with the repair, protection and strengthening of concrete has experienced explosive growth. This has been driven by the need to reverse the deterioration of, damage to, and defects in concrete structures as well as by changes in building use and code requirements. Accordingly, there is great need to improve the materials and techniques used in repair and strengthening.[2] Polymers have been used as additives in cement mortars and concrete since the 1920s. Since then, there has been considerable development of polymer modification for cement and concrete. Commercial products, called cement admixtures, are used in many applications in the construction industry from walls to roads.[3]

Over the past twenty years, many different polymers have been used in a range of applications in the repair and maintenance of buildings and other structures. Without the unique properties of some of the polymer systems, many of the repairs undertaken would, without doubt, have been much more costly and have taken much longer to carry out. The polymers used in concrete repair consist principally of two different types of materials: (Polymers used to modify cementitious systems, and reactive thermosetting resins, mainly epoxy and unsaturated polyester resins).[4] Replacement of concrete buildings, bridges, roadways and other structures is becoming more and more expensive as costs of materials and labor continue their upward spiral. More attention is now being directed to development of materials for repair and restoration of concrete since, when effective, they represent an increasingly economical solution Among the materials being more closely evaluated and more widely accepted are the epoxy resins. Used alone or in combination with other standard construction materials, epoxies have made repairs possible where before only replacement was considered. Although epoxies themselves are somewhat costly, their total cost often becomes minimal when the quality of repair achievable with other materials is considered. It becomes practically insignificant when compared to the cost of new construction.[5]

Polymer-modified or polymer cement mortar (PCM) and concrete (PCC) are a category of concrete-polymer composites. Polymer modified or polymer cement paste, which is prepared without any aggregate, is sometimes used. Polymer-modified mortar and concrete are prepared by mixing either a polymer or monomer in a dispersed, powdery, or liquid form with fresh cement mortar and concrete mixtures, and subsequently curing. Several types of polymer-modified mortars and concretes, i.e., latex-redispersible polymer powder-, water-soluble polymer-, liquid resin, and monomer-modified mortars and concretes, are produced by using the polymers and monomers.[6] The main application of polymer cements is in concrete repair. The function of the polymer was mainly to reduce concrete permeability and to increase resistance to chloride penetration, toughness and adhesion. .[7]

II. Aims

The aim of this work is to investigate the possibilities of making a new repairing materials by full replacing the water with polymer material and finding out the suitable the suitable percent of mixing and which percent should be avoided to use in bonding the concrete to reduce the cost of concrete repairing.

III. Experimental Procedure

3.1. Materials

3.1.1 Cement:

The cement that used is ordinary Portland cement, commercially known **(TASLUJA)**. It was stored in dry place to minimize the effect of humidity on cement properties and it was tested in (National Center for Laboratories and Construction Research). The chemical and physical properties of cement are given in table (1). It is matched by the Iraqi Reference Guide indicative number (198) and the Ministry of Planning / Central Agency for Standardization and Quality Control Manual 198/1990. [8]

Table (1): Chemical and physical properties of Portland cement.

Chemical composition			**Physical composition**		
Item	**Content %**	**Spec. Limit**	**Item**	**Test result**	**Spec. Limit**
SiO_2	20.03		Fineness (m^2/kg)	370	230
Al_2O_3	4.35		Autoclave exp.	0.32	0.8%
Fe_2O_3	3.17		Compressive strength (MPa) 3-days age	29.5	15.0
CaO	63.66				
MgO	1.63	5.0 Max			
SO_3	2.3	2.8 Max	Compressive strength (MPa) 7-days age	35	23.0
L.O.I	1.9	4.0 Max	Time of setting Initial (min.)	35	45
I.R.[Insoluble Residue %]	0.99	1.5	Time of setting Final (hour)	5.25	10 Max.

3.1.2 Natural Sand Aggregate

The fine aggregate used in study is according to the Iraqi specification No. 45 of 1984 for Cement. Brought from Ukhaydir area where they were bringing models that are all located within the area of the second gradient specification under Iraqi specification[11] as shown in the table (2)**.**

Table (2): Grading of fine aggregate.

Sieve size (mm)	**% Passing by Weight**	**Specific Limit**
4.75	95.3	90-100
2.36	83.7	70-100
1.18	71.9	55-90
0.60	51.8	53-59
0.30	21.2	8-30
0.15	4.7	0-10
Percentage of salts%	0.4	≤0.5

3.1.3 Polymer

The epoxy was resin group type Quickmast 105 (DCP) Company / Jordan. Specific gravity and viscosity of the epoxy resin were 1.04 and 1 poise respectively at 35°C. The ratio between resin and hardener for this epoxy is 3:1 by weight.

IV. Experimental Work

In this work, different mixes of polymer-mortar were prepared to study their mechanical properties of polymer-mortar as a repairing material. Utilization of polymer composite as a repairing material for cracked structural concrete. Experimental work and test procedures are detailed in this work.

Two sets of mixtures were prepared that consist of mortar and polymer to fabricate the polymer-mortar composites. The first set include mortar with ratio (1:1) (cement-sand) without water, while the other set include mortar with ratio (1:2) (cement-sand) without water. Each set was consist of different percentage of polymer (50:50, 40:60 and 30:70). The polymer was epoxy which is added to the mortar after mixing the resin with the hardener in proportion of (3:1). The polymer-mortar mixtures were illustrated in Table (3).

Table 3. Polymer-Mortar Mixtures, [%]

Specimen No.	Mortar %	Epoxy %	Mixture %	Dimensions (mm)	
				Compression	Flexural
1	1:1	1:3	50:50	50x50x50	100x25x25
2	1:1	1:3	40:60	50x50x50	100x25x25
3	1:1	1:3	30:70	50x50x50	100x25x25
4	1:2	1:3	50:50	50x50x50	100x25x25
5	1:2	1:3	40:60	50x50x50	100x25x25
6	1:2	1:3	30:70	50x50x50	100x25x25

The polymer-mortar with different proportions as given in table (3), was prepared by using electrical mixer (Automix, Controls Co. Italy). Firstly the resin mixed with hardener for 2-5 minutes, then cement and sand were separately mixed for 5 minutes. The polymer-mortar mixture were obtained by mixing them for 10 minutes until achieving a homogeneous mix. After complete mixing, the polymer-mortar was poured in molds, the molds were coated with mineral oil to prevent adhesion of polymer-mortar .Polymer-mortar casting was accomplished in three layers. Each layer was compacted by using a vibrating device (Viatest Co. German), for 1-1.5 minutes until no air bubbles emerged to the surface of the casting. The specimens were de-molded after 24±2 hours from casting, and then complete curing at room temperature for seven days to ensure full curing until the time of testing.

V. Tests

Three types of tests for polymer-mortar composites were carried out. The destructive tests consists of compressive strength, flexural strength and bonding compressive strength.

5.1 Destructive Tests

5.1.1 Compressive Strength Test

The compression test was determined according to American Society for Testing and Materials . ASTM C109/C109M-13 (Using 2-in. or [50-mm] cube Specimens).[12] The specimens are loaded uniaxily by the universal compressive machine (Viatest CO. Cyber-Tronic, model DPC 3000. German) of 3000 kN capacity at loading rate of 8.1 KN per second. The test was carried out for all proportions at the same rate of loading.

5.1.2 Flexural Strength Test

This test methods are according to the ASTM D790-02 [13]. A bar of rectangular cross section rests on two supports and is loaded by means of a loading nose midway between the support, using calibrated testing machine (Sercomp, Controls Co. Italy).

5.1.3 Bond Strength test

This test was applied to determine the bond strength of concrete cylinder specimen using polymer-mortar composites as a repairing material under the ASTM C882/C 882M.[14]

The bond strength is determined by using the polymer-mortar to bond two equal sections of a [150 by 75-mm] Portland-cement mortar cylinder, each section of which has a diagonally cast bonding area at a 30° angle from vertical as shown in figure (1).

Fig. 1. Two equal sections of a [150 by 75-mm] Portland-cement mortar cylinder.

Wrap the cylinder parts by using tape and also using plaster to ensure the stability of the parts and also to prevent mixture of polymer-mortar bleeding out from the bonded area. Test procedure starts by mixing the polymer-mortar composite in the proportions as in table (3). A mixing time of 3 minutes should be satisfied. The bond should keep the polymer-mortar mixture injected into a hole, at the bond-line, while keeping the joint horizontal. The assembly should secure with sufficient additional masking tape placed around the wrapped tape and plaster, and making sure that the joint is entirely filled. The bonded cylinder must kept horizontally for 48 hours, then remove all the masking tape. After suitable curing of the bonding agent (for 7 days) , cap the specimens immediately after removal from curing.[15] To ensure that the test cylinder has smooth, parallel, uniform, bearing surfaces that are perpendicular to the applied axial load during compressive strength testing using (Capping).[15] This method is done by remove such coatings or deposits. If necessary, the ends of a specimen may be slightly roughened with a steel file or wire brush to produce proper adhesion of the cap. If desired, capping plates may be coated with a thin layer of mineral oil or grease to prevent the capping material from adhering to the surface of the plate. Prepare sulfur mortar for use by heating to about 130°C. The capping plate or device should be warmed before use to slow the rate of hardening and permit the production of thin caps. Oil the capping plate lightly and stir the molten sulfur mortar immediately prior to pouring each cap. The ends of moist cured specimens shall be dry enough at the time of capping to preclude the formation of steam or foam pockets under or in the cap larger than 6 mm in diameter. This method is shown in figures (2 and 3). To ensure that the cap is bonded to the surface of the specimen, the end of the specimen shall not be oiled prior to the application of the cap.

Fig. 2. Capping plate and device.

Fig. 3. Capping furnace (Controls Co.) Italy.

After the completion of Capping process leave the specimens for a period of 21 days as in figure (4) and then test the specimens in compression accordance with test method.

The area of the elliptical bonding surface of the test cylinders specified in this test method is [9116 mm^2].[14]

After suitable curing of the bonding agent, the test is performed by determining the compressive strength of the bonded cylinder.

Fig. 4. Capped cylinders.

VI. Results And Discussions

6.1 Compressive Strength Test

The compressive strength is considered one of the most important properties of polymer-mortar composites. Generally it is the main characteristic value to assess composite quality in the national and international codes. For this reason, it is if special interest to investigate whether the changes in the mixture composition will affect the early and later compressive strength. The compressive strength results for all proportions are shown in table(4).

Table 4. Results of compressive strength for all proportions.

		Compressive Strength (MPa)	
Polymer Type	**Designation**	**1:1**	**1:2**
Quickmast 105	50:50 at room temperature	87.496	81.464
Quickmast 105	40:60 at room temperature	57.492	70.1996
Quickmast 105	30:70 at room temperature	102.889	101.663

The following observations can be concluded from above results:

- Polymer-mortar composites show an increase in compressive strength, this behavior can be explained due to the presence of polymer in the composite; therefore this property helps to increase the compressive strength.
- Polymer-mortar with low polymer content in the composite having higher compressive strength as in 30:70 proportion, this is due to the good bonding and also good strength.
- The polymer-mortar with 40:60 ratio showed a decrease in compressive strength, this is because of reducing in the adhesion between polymer and mortar particles.
- The percentages with 50:50 gives a moderate values and this behavior this due to the ratio of mortar to the polymer.
-

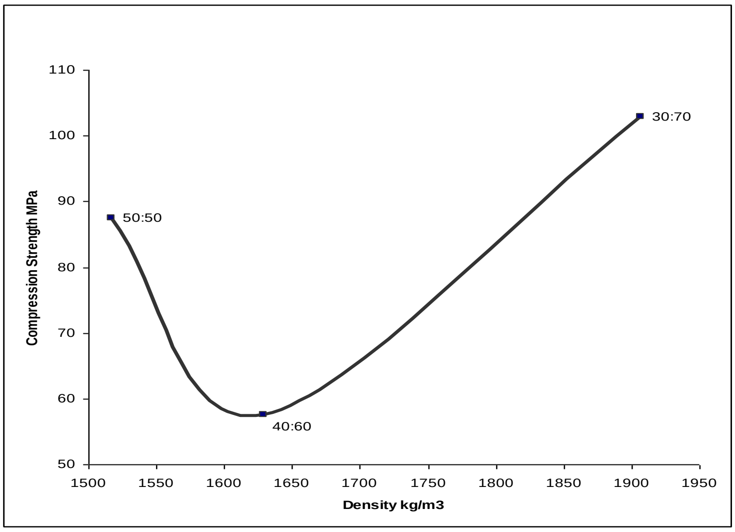

Fig.5. Compressive strength-Density for 1:1 Quickmast 105 at room temperature

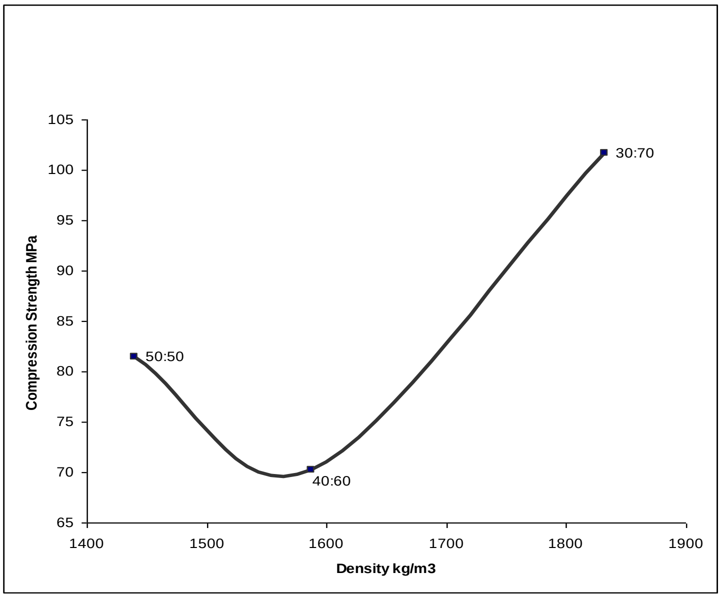

Fig.6. Compressive strength-Density for 1:2 Quickmast 105 at room temperature

- From fig.5. the highest compressive strength at 30:70 polymer-mortar composite (Quickmast 105) is 102.889 MPa for 1:1 at room temperature.
- From fig.6. the highest compressive strength at 30:70 polymer-mortar composite (Quickmast 105) is 101.663 MPa for 1:2 at room temperature.

Figure (7), illustrate the comparison between proportions of polymer-mortar ratios of polymer type Quickmast 105 at room temperature**.**

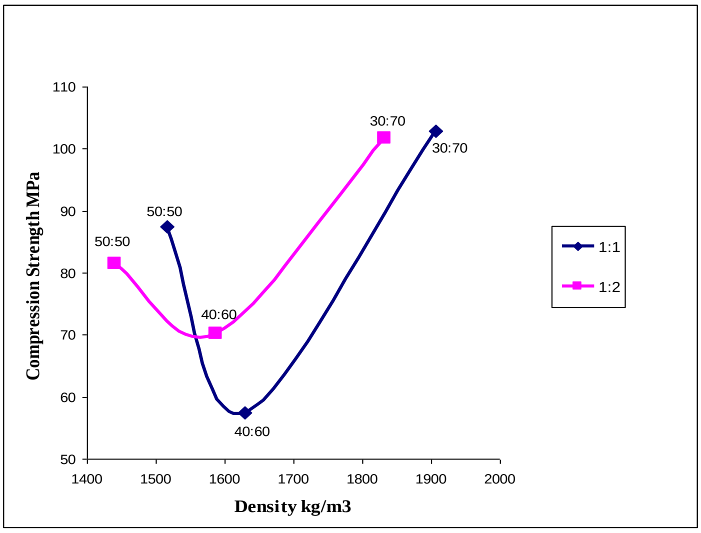

Fig.7. Comparison between the compressive strength of different proportions of polymer-mortar composites at room temperature.

The comparison diagrams showed we can conclude these observations:

- Polymer-mortar with mortar ratio 1:1 is better than that for 1:2 except that for 1:2 of polymer- mortar ratio 30:70 gives higher value.
- For mortar with 1:1 ratio the proportion of 40:60 is the lowest value for two ratios of mortar.

6.2 Flexural Strength Test

The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress. A mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load. The transverse bending test is most frequently employed, in which a specimen having a rectangular cross-section is bent until fracture or yielding.

The flexural strength results for all proportions are shown in table (5). Polymer with mortar in different ratios, which are presented in figures (8 and 9).

Table 5.Results of flexural strength for all proportions.

		Flexural Strength (MPa)	
Polymer Type	**Designation**	**1:1**	**1:2**
Quickmast 105	50:50 at room temperature	48.6528	43.1808
Quickmast 105	40:60 at room temperature	48.8064	48.9792
Quickmast 105	30:70 at room temperature	57.648	60.5184

The following observations can be concluded from above results:

- ❖ Polymer- mortar with low polymer content in the composite having higher flexural strength as in 40:60 and 30:70 proportions, this is due to the high ratio of mortar to the polymer this cause a good penetration of polymer to the mortar and this may increase the surface area of the particles and also increase the adhesion strength.
- ❖ The polymer- mortar with 50:50 ratio showed a decrease in flexural strength, this is because of low density and also low compacting between particles.
- ❖ The percentages with 40:60 gives a moderate values and this behavior due to the good bonding and also good strength.

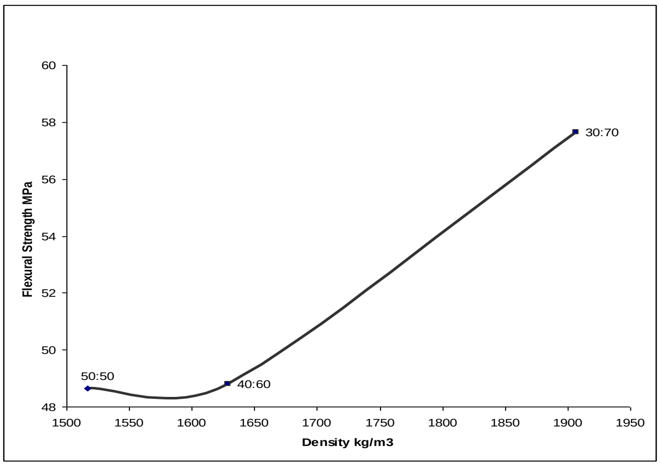

Fig. 8. Flexural strength-Density for 1:1 Quickmast 105 at room temperature

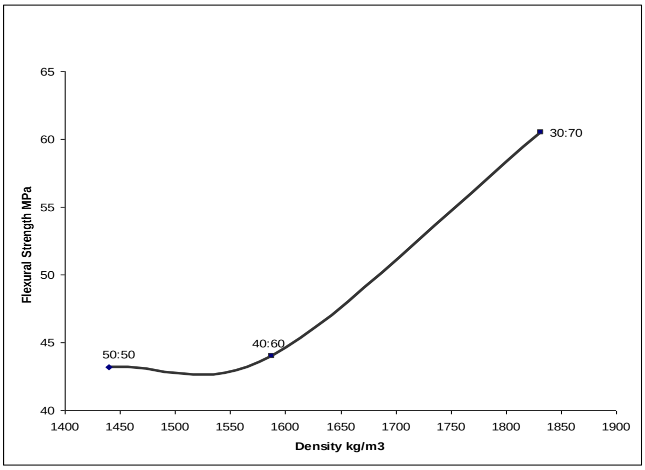

Fig.9. Flexural strength-Density for 1:2 Quickmast 105 at room temperature

- From fig.8. the highest flexural strength at 30:70 polymer- mortar composite (Quickmast 105) is 57.648 MPa for 1:1 at room temperature.
- From fig.9. the highest flexural strength at 30:70 polymer- mortar composite (Quickmast 105) is 60.5184 MPa for 1:2 at room temperature.

Figure (10), illustrate the comparison between proportions of polymer- mortar ratios of polymer type Quickmast 105 at room temperature.

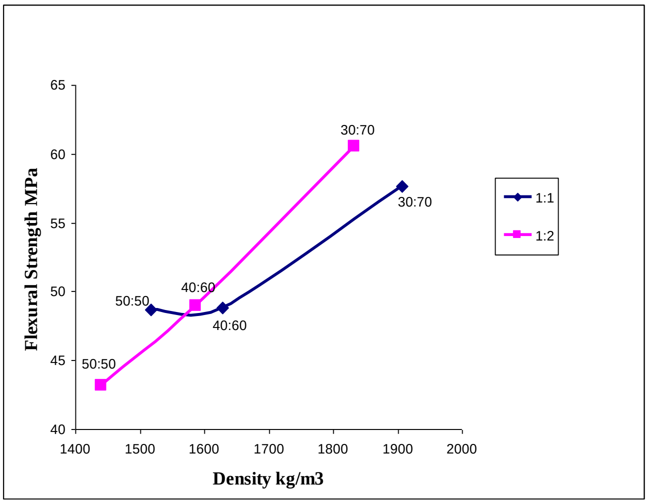

Fig.10. Comparison between the flexural strength of different proportions of polymer-mortar composites at room temperature.

The comparison diagrams showed these observations:

- Polymer-mortar with mortar ratio 1:2 is better than that for 1:1 at room temperature except for 50:50 proportion is lower than that for 1:1.

6.3 Bond Strength of Repaired Concrete Test

Calculate the bond strength of the resin bonding system by dividing the load carried by the specimen at failure by the area of the bonded surface the area of the elliptical bonding surface of the test cylinders specified in this test method is (9116 mm^2). [39] The bond strength after fracture taking place in the main cylinder while the bond region is not affected, this indicate to good bond strength and good repairing material as shown in figure (11), the results are shown in figure (12), and figure (13) for 1:1 and 1:2 respectively.

Fig.11. The bond strength of polymer-mortar.

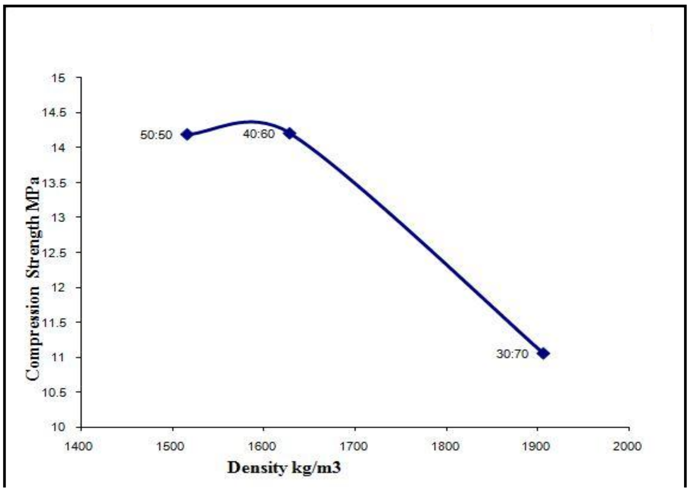

Fig. 12. Bonding Strength – Density diagram for 1:1 Quickmast 105

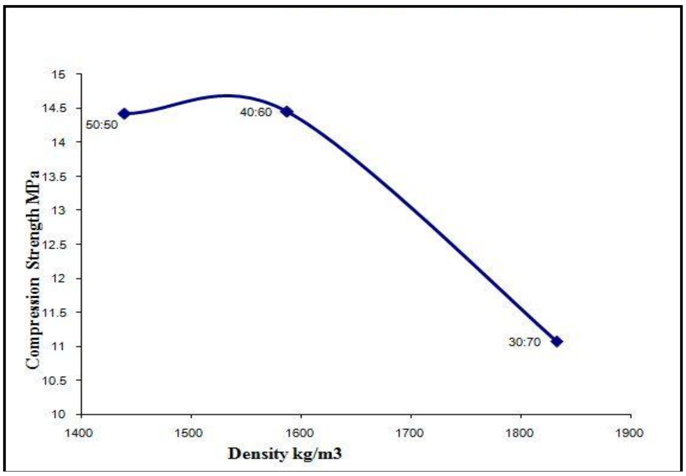

Fig. 13. Bonding Strength – Density diagram for 1:2 Quickmast 105

The following observations can be concluded from above figures:

- ❖ Polymer-mortar with low polymer content in the composite having low bonding compressive strength as in 30:70 proportion, this is due to the high ratio of mortar to the polymer this cause a low adhesion and low strength.
- ❖ The percentages with 50:50 gives a moderate values and this is because of low density and also low compacting between particles.
- ❖ The polymer-mortar with 40:60 ratio showed a higher bonding compressive strength, this is this behavior due to the good bonding and also good strength.
- ❖ The bonding strength of 1:2 mortar ratio specimens increased, this is due to good penetration of polymer between sand particle since the sand is added in a high percentages, and so increase the bonding strength between particles.

VII. Conclusion

The following main conclusion were achieved from this study, get a new type of concrete repair materials can be achieved from mixing the polymer with mortar, proportionality between the cement and sand as a mortar and between the polymer and mortar plays a major role in adhesion, the adhesion and strength are considered key factors in the bonding and portability to repairs and also the addition of polymer to mortar increases the compression and flexural strength and reduces their brittle nature.

REFERENCES

[1] Lee Eng Hing, Application of polymer in concrete construction, Faculty of Civil Engineering University Technology Malaysia, November, 2007

[2] Novel cement-based composites for the strengthening and repair of concrete structures Construction and Building Materials, Volume 41, April 2013, Pages 365-373

[3] Edward M Petrie, Polymer modified Portland cement adhesives and grouts, Polymer Modified Cement Special Chem. Sep 17, 2012.

[4] Shaw, J.D.N, Polymers for concrete repair. Civil Engineering, 63–65., 1993.

[5] Epoxies for concrete repair and restoration, By Concrete Construction Staff, The Aberdeen Group, 1979.

[6] Handbook of Polymer-Modified Concrete and Mortars Properties and Process Technology. Yoshihiko Ohama. Copyright. William Andrew Inc. All rights reserved 1995.

[7] Ivan Razl, Flexible Polymer-Cement Based Repair Materials and Their Applications. Concrete Repair Bulletin, 2004.

[8] Iraqi Reference Guide indicative (198) and the Ministry of Planning / Central Agency for Standardization and Quality Control Manual 198/1990.

[9] ASTM C138/C138M Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete.2010

[10] British standard BS1881 : part 203:1986.2003

[11] ASTM D2240 - 05(2010) Standard Test Method for Rubber Property Durometer Hardness Book of Standards Volume: 09.01

[12] ASTM C 109/C 109M Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens) August 2008.

[13] ASTM D 790 – 02 Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.2002

[14] ASTM C 882/C 882M Standard Test Method for Bond Strength of Epoxy-Resin Systems Used With Concrete By Slant Shear.2008.

[15] ASTM C 617 – 98 Standard Practice for Capping Cylindrical Concrete Specimens. 2003.