The Mechanical Properties of Polymer-Mortar Composites

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Abstract

The polymer-mortar composites have several benefits, including corrosion resistance, high strength and modulus values compared to their low density, acceptable deformability, tailored design and excellent formability. This enables the fabrication of new elements and the structural rehabilitation of the existing parts made of traditional materials. In this work two sets of mixtures were prepared that consist of mortar and polymer to fabricate the polymer-mortar 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 epoxy which is added to the mortar after mixing the resin with the hardener in proportion of (1:3). Each set consists of different percentage of polymer (50:50, 40:60 and 30:70). to obtain Several results were obtained such as density, were the highest value was about 1906.4 kg/m^3 for (1:1). The behavior of non-destructive test (UPV) was differ from that of density were the highest value was about 3521.12 m/sec for (1:2). The highest hardness of composites was 98.2 for (1:1). The destructive tests as compressive and flexural strength, the highest compressive strength was about 102.889MPa and the highest value of flexural strength was about 57.648MPa for (1:1).

Key Words: Polymer, mortar, composite, polymer – mortar

الخصائص الميكانيكية مركبات البوليمر- ملاط

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الخلاصة

مركبات البوليمر – ملاط لها فوائد عدة، بما في ذلك مقاومة للتآكل، متانة عالية ومعامل المقاومة عالي مقارنة مع كثافتها الواطئة، التشوه الحاصل يكون مقبول، دقة التصميم، قابليه التشكيل ممتازة . هذا يمكن من تصنيع عناصر جديدة وإعادة تأهيل هياكل الأجزاء المصنعة من مواد تقليدية . تم في هذا البحث أخذ مجموعتين من الخلطات التي أعدت من الملاط والبوليمر لتكوين مركب البوليمر- ملاط. المجموعة الأولى تشمل ملاط بنسبة (1:1) (الأسمنت-الرمل) بدون ماء،و أخرى تشمل ملاط بنسبة (1:2) (الأسمنت-الرمل) بدون ماء . البوليمر الذي أضيف إلى الملاط هو ايبوكسي يضاف بعد خلط الراتنج مع المصلد بنسبة (1:3). أضيف البوليمر الى كل مجموعة من الملاط بنسب مختلفة (50:50، 40:60 و 30:70). حيث تم الحصول على عدة نتائج منها، نسبة البوليمر التي يضاف إلى الملاط يؤثر على الخصائص. تجانس الخليط يلعب دورا رئيسيا في سلوك المركب ويمكن تحقيق خصائص مختلفة وفقا لنسبة الاسمنت- رمل . و يزيد من مقاومة الشد والانحناء من الملاط وأيضا يقلل من طبيعتها الهشة. وتم الحصول على العديد من النتائج فعند قياس الكثافة كانت أعلى قيمة حوالي 1906.4 كغ / م^3 لنسبة (1:1). هذا السلوك يختلف عند فحصه بالاختبارات اللاأتلافية (UPV) لقياس سرعة

الموجة في النماذج حيث أعلى قيمة كانت حوالي 3521.12 متر / ثانية لنسبة (1:2). أما عند اختبار الصلادة فإن هي 98.2 لنسبة (1:1). عند فحصه بلاختبارات الأتلافية أعلى قيمة لمقاومة الانضغاط حوالي MPa 102.889 و أعلى قيمة لمتانة الانحناء حوالي 105 MPa 57.648 لنسبة (1:1).

1. Introduction

Polymers have been used as additives in cement mortars and concrete since the 1920s when natural rubber latex was added to road paving materials. 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. A significant volume application for polymer modified Portland cement is adhesive and grout for attaching ceramic tiles to walls and flooring. There are several different types of polymers that have been used as additives in cement and concrete. These can be broadly divided into four groups: polymer latex (or polymer dispersion), redispersible polymer powder, water-soluble polymer, and liquid polymer. There are many different families of polymers that are associated with each type as shown in figure 1. [1] [2]

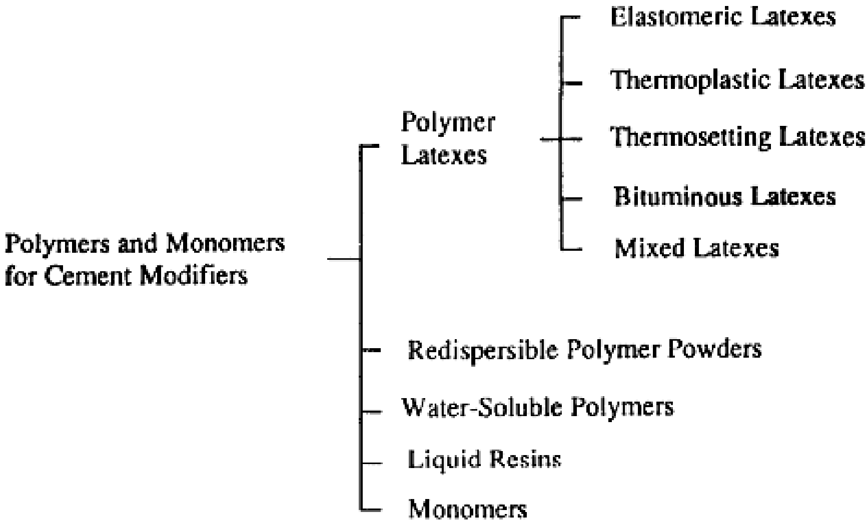


Fig.1. Polymers and monomers for cement modifiers.

Polymer modified concrete or mortar is a composite material consisting of two solid phases: the aggregates which are discontinuously dispersed through the material and the binder which itself consists of a cementitious phase and a polymer phase. According to the volume fraction of the polymer in the binder phase the material shifts from PCC, i.e. polymer cement concrete, to PC, i.e. polymer concrete.[3]

Ivan Razl. 2004 [4]. Studied flexible polymer modified cement (FPMC), polymer modification of cement paste changes the properties of mortar and concrete. These effects depend mainly on the polymer content, expressed as polymer/cement ratio, the type of polymer and also the design of the mortar or concrete. Typical effects of polymer modification on performance of Portland cement mortars and concrete. Compressive strength (Decreased or increased), Tensile strength (Increased), Fracture Toughness (Increased), Adhesion (Increased), Modulus of Elasticity (Decreased or increased), Drying shrinkage (Decreased or increased), Water vapor permeability (Decreased), Hydraulic permeability (Decreased), Creep (Decreased or increased), CO_2 permeability (Decreased), Chloride penetration resistance (Decreased), Chemical resistance (Increased in some chemicals). The tensile elongation is also increased, but the ultimate tensile strain does not increase much over 1%.

Muhammad Farhan Arooj, et.al. 2011[5]. focused on the availability and use of polymer-modified concrete under local conditions in Pakistan. The results demonstrated that the strength of polymer-modified concrete is greatly influenced by the mixing ratio of ingredients. A ratio of 4:4:1 by weight of PVA, AG and CMC showed excellent results in bearing flexural tension stresses of 1200 psi which was three times more than the ordinary concrete. The tensile strength of ordinary concrete repaired with the above ratio of polymer-modified concrete was 550 psi, which was even more than the tensile strength of unrepaired un-broken sample. It also showed excellent bonding with old concrete. Cost of altered polymer for best ratio of 4:4:1 was only Rs 10/Kg, which was 4 to 10 times less than cost of ordinary polymer available in the market. Thus technical and economic feasibility of using modified polymer concrete for the repair of concrete structures under local conditions was established.

Meethaq M. Abed et al. 2013 [6]. developed the unsaturated polyester composite was used for binding the aggregates. In the composition were introduced near the silica foam as filler and glass fibers .Some mechanical properties of polymer concrete have been investigated, by destructive and non – destructive method. The experimental results of non–destructive method were correlated with compressive strength. Compression strength values increase with increasing of fillers percent at75% and Pulse velocity values increase with increasing of Compression strength. The fiber percentage and silica foam was constant, the unsaturated polyester resin and the Silica sand dosages were varied. This research was conducted at 26KHz.

Sahil Navlani. 2014[7]. Described the polymer concrete composites and its application as repair, protective coatings (including industrial floors) and precast elements. An ultrasonic test method was selected to evaluate these applications. Due to good chemical resistance and high initial strength and modulus of elasticity, industrial use of Polymer Concrete has been mainly in overlay's and repair jobs. Processing technology that will provide better workability, placement, & finish ability. Development of adequate mixture proportioning methods. More efficient aggregate packing. Less resins incorporated into the mixture. The concrete-polymer composites with high performance, multi functionality and sustainability are expected to become the promising construction materials.

2. Aims

In this work, find the possibilities of making polymer-mortar composites and measuring some of its properties with evaluating the best percentage of addition.

3. 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	Compressive strength (MPa) 7-days age	35	23.0
SO_3	2.3	2.8 Max	Time of setting Initial (min.)	35	45
L.O.I	1.9	4.0 Max			
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[8] 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 resin group type Quickmast 105 (DCP) Company / Jordan used. Specific gravity and viscosity of the epoxy resin were 1.04 and 1 poise respectively at 35^{o}C. The ratio between resin and hardener for this study was 3:1 by weight.

3.2. Experimental Work

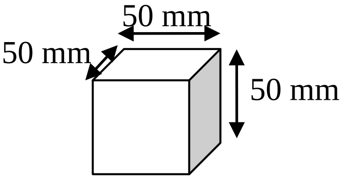
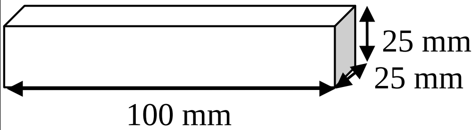
Two sets of mixtures were prepared that consist of mortar and polymer to fabricate the polymer-mortar composite. The first set includes mortar with ratio (1:1) (cement-sand) without water, while the other set include mortar with ratio (1:2) (cement-sand) without water. Each set consists of different 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 (1:3). The polymer-mortar composite mixture are illustrated in Table (3).

Table 3. Polymer-Cement Mixtures, [%]

Specimen No.	Mortar %	Epoxy (Hardner:Resin) %	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 dimensions of specimen are shown in table (4) according to the ASTM standards.

Table 4. The dimensions of specimens.

Test type	Test Specimen Specification	Standardization Code
Compression		ASTM C109/C109M-13
Flexural		ASTM D 790 - 02

The polymer-mortar with different proportions as given in Table 4, was prepared by mixing firstly the resin with hardener, then after complete homogenization the polymer-mortar were introduced in the mixture. An electrical mixer was used in preparing the mixtures to achieve a suitable homogeneity. After mixing, the polymer mortar was poured in molds ,after the molds were coated with mineral oil to prevent the adhesion with the polymer-mortar composite. Polymer-mortar casting was accomplished in three layers. Each layer was compacted by using a vibrating device (Viatest Co. German) for 1-1.5 min. until minimum air bubbles emerged to the surface of the casting. The following mechanical characteristics were experimentally tested: compressive strength on cube sample of 50 mm sizes, flexural strength samples of sizes 100×25×25 mm as shown in **fig.(2)** according to standard prescriptions.

Fig. 2. Specimens after de-molding.

4. Tests

4.1 Density Test

The density of polymer-mortar composite was determined for each proportion of cubes in (kg/m^3), which is found by weighting (mass in kilograms) the cubes and dividing the values on the volume of these cubes (50x50x50) mm.

4.2 Hardness Test

According to the ASTM D 2240, the hardness test was carried on by using Digital durometer pocketsize model for Shore A hardness testing digital hand-held hardness tester. The hardness of polymer-cement composite cubes was found by taking three readings on each face of the cube except the face exposure to air with integrated probe.

4.3 Ultrasonic Pulse Velocity Test

This test was carried out according to the British standard BS1881 : part 203:1986, using the portable ultrasonic non-destructive indicating tester (PUNDIT Lab PROCEQ Co.) Switzerland. Two transducers are fitted to the instrument cables, one acts as a transmitter for the ultrasonic pulses, and the second acts as the receiver. Both transducers are held against the surface of the specimen using a coupling agent to ensure good pulse transmittance. In this test a pulse of longitudinal vibration with resonant frequencies of 54KHz was produced by an electro-acoustical transducer and then converted into an electrical signal by receiver transducer. The transit time of the pulse is applied by an electronic timing circuit. Grease or petroleum jelly was applied between the tested surfaces of the specimen and contact faces of the transducers to ensure good contact. The transducers can be used above and below a concrete member when looking for voids. For surface cracks or defects, both transducers are placed on the same surface, e.g. on the top face of a slab.

The pulse velocity (V) in (m/sec.) was calculated as follows:

$$V=L/t$$

Where:

L= path length (m)

t= transit time (micro sec.)

4.4 Compression Test

The compression test was determined according to American Society for Testing and Materials . ASTM C109/C109M-13.[41] 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 specimens at the same rate of loading.

4.5 Flexural Strength Test

These test methods according to ASTM D790-02. 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) as shown in fig.(3).

Fig.3. Flexural testing machine.

5. Results and Discussions

The characteristics of polymer-mortar composite was experimentally determined namely: density, hardness , velocity, compressive strength, and flexural strength for polymer-cement composite tested at room temperature.

5.1 Density Test

The bulk density of polymer-cement of specimens were measured, as shown in table (5) . The results show that the percentage (30:70) of polymer-cement composite is the highest density. This can explained by the large proportion of mortar over the polymer proportion.

Table 5. Bulk density of polymer-cement specimens.

Mortar ratio / Polymer-mortar ratio	Density (kg/m^3)	
	1:1	**1:2**
50:50	1516.8	1440
40:60	1628.8	1587.2
30:70	1906.4	1832

5.2 Hardness Test

The variation of shore A hardness of samples prepared with different percentages and ratios was shown in these schemes give the behavior of the hardness of the specimens of the polymer - mortar at room temperature and proportions of 1:1 for the cement to sand, as shown in figure (4) and also 1:2 as shown in figure (5). The results show that the percentage (50:50) of polymer-mortar composite is the highest hardness. each point in the figure is mean the percentage of polymer to mortar. The decrease in hardness could be interpreted that he gets because of the decrease in cohesion and adhesion between particles mortar itself and also decrease the proportion of the polymer. Hardness is a surface property whenever the surface with a high specification was high hardness, note that the ratio of 30: 70 is high due to increased surface hardness and homogeneity.

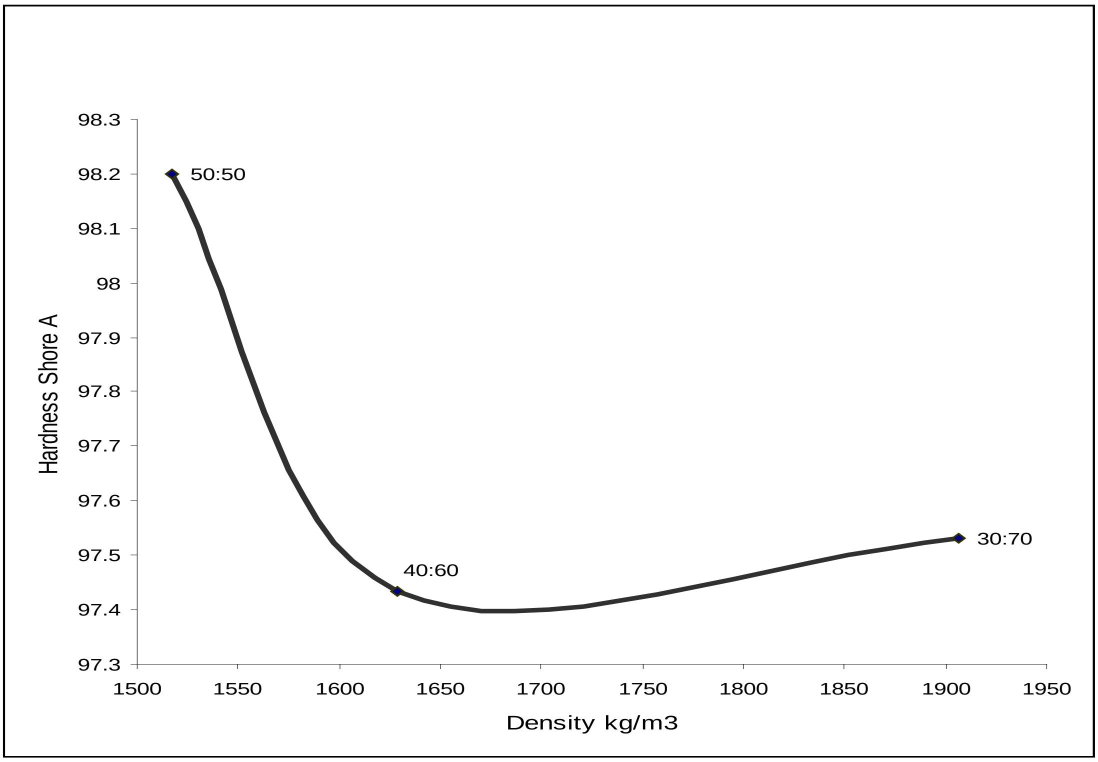


Fig. 4. Shore A hardness of specimens prepared with 1:1 ratios of cement to sand.

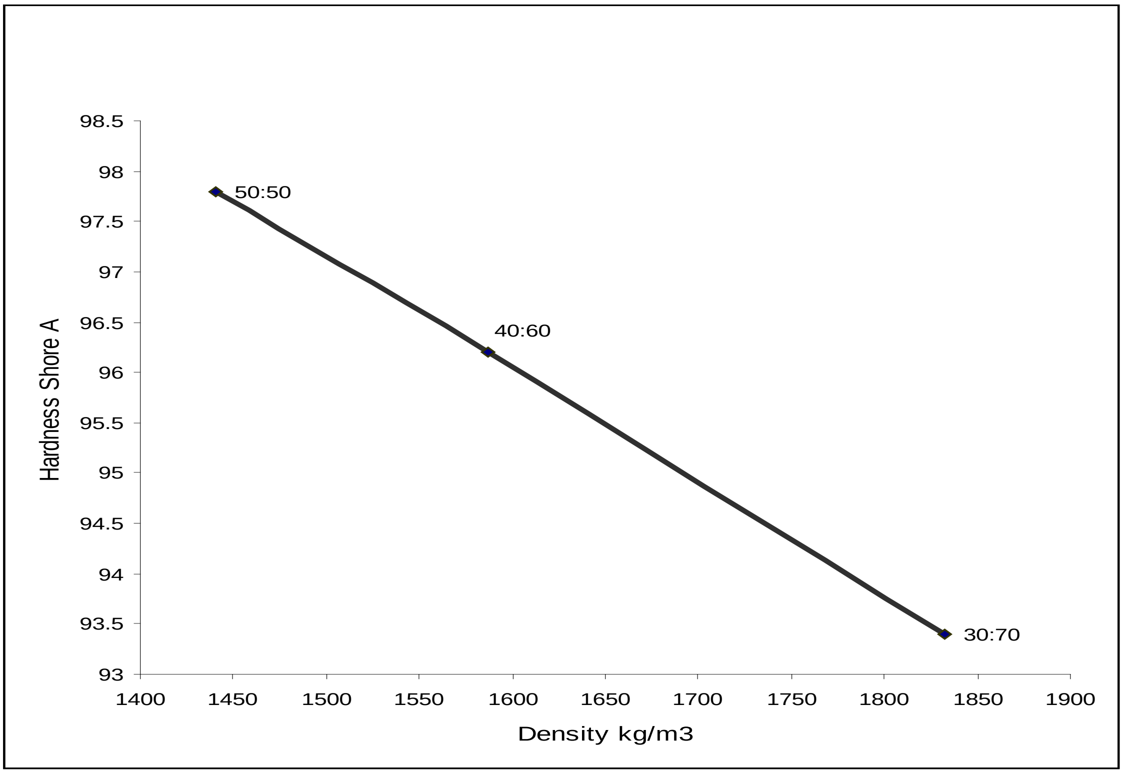


Fig. 5. Shore A hardness of specimens prepared with 1:2 ratios of cement to sand.

5.3 Ultrasonic Pulse Velocity Test

The homogeneity, cracks, voids …etc. can be detected by carrying the ultrasonic pulse velocity test as shown in figure (6) and figure (7). The velocity of the specimens have different values according to the polymer percentages. This can be clarified by inhomogeneity, that cause delaying in the ultrasonic pulse. Proportions of 1:1 for the sand to cement, when the density increase the velocity is increased as in points 50:50 and 40:60 but when looking for 30: 70 is decreased due to the lack of adhesion and the lack of homogeneity as shown in figure (6) and also 2:1 the better velocity at 30:70 as shown in figure (7). This difference is a result of the difference in percentages between sand and cement.

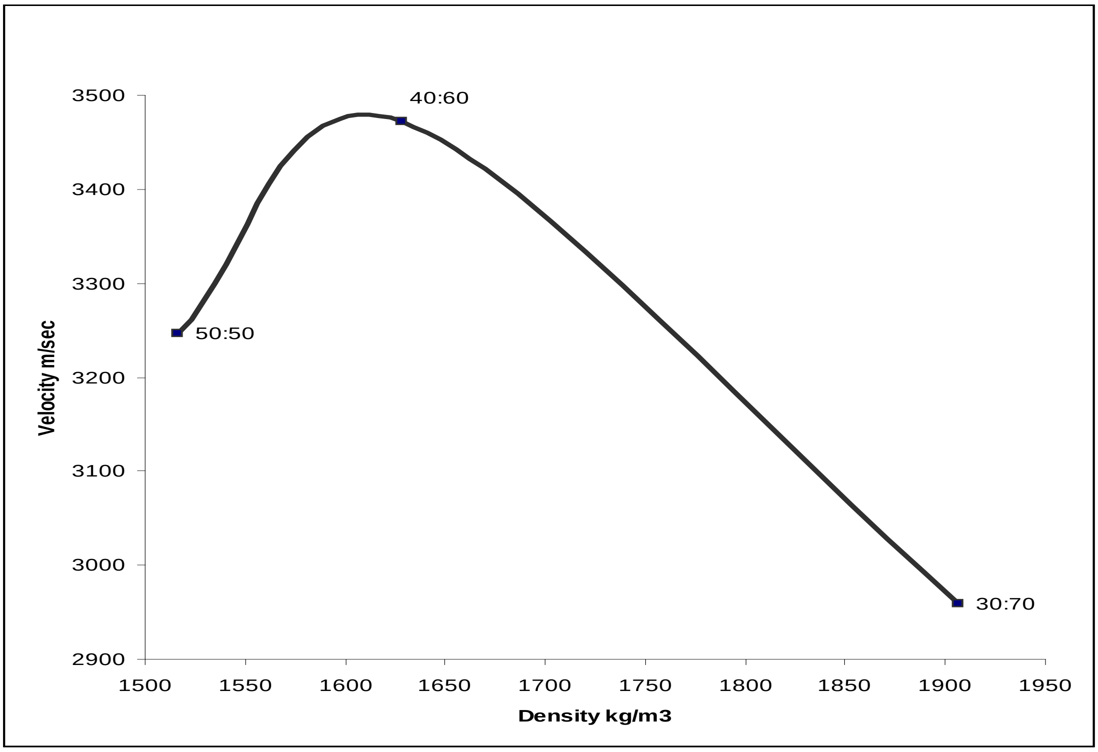


Fig. 6. Velocity of specimens prepared with 1:1 ratios of cement to sand.

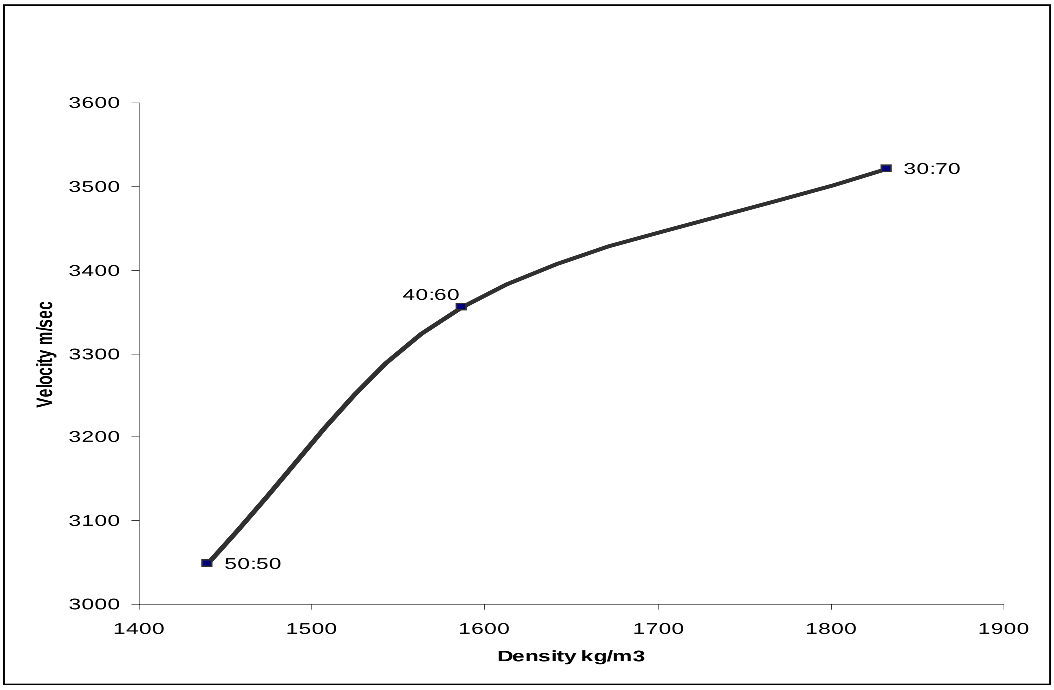


Fig. 7. Velocity of specimens prepared with 1:2 ratios of cement to sand.

5.4 Compression Strength Test

The following observations can be made from the experimental results:

a) The values of compressive strengths for polymer-Mortar for 1:2 cement to sand ratio (Fig. 8) vary between 57.492 MPa for specimen of 1:1 (40:60) and 102.889MPa for specimen of 1:1 (30:70), and the highest compression strength at specimen of 1:1 (30:70) it is 102.889 MPa. The point 30:70 show good compressive strength, this behavior can be explained due to high ratio of mortar, which led to the compacting well as this behavior is considered good to distribute the load well and increase the compressive strength. The polymer- mortar with 40:60 ratio showed a decrease in compressive strength, this is because of reducing in the bond strength between polymer and mortar particles.

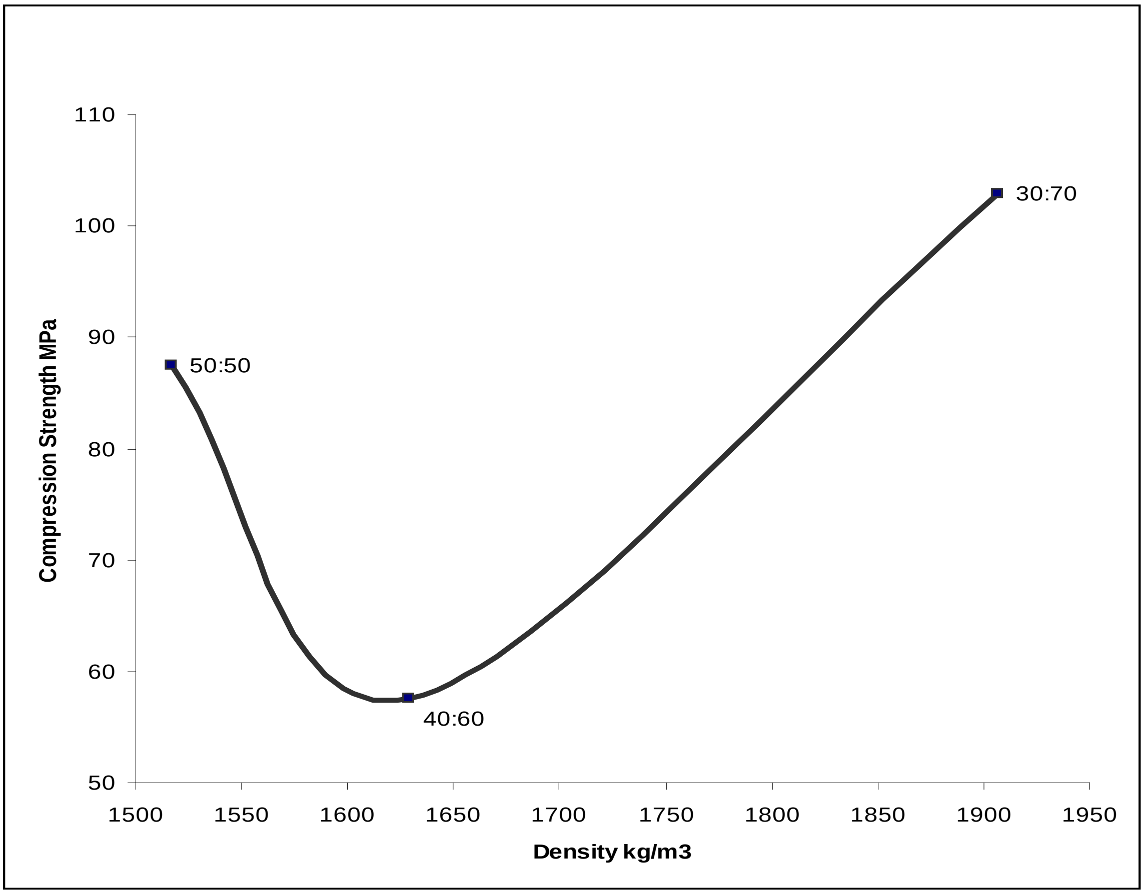


Fig.8. Compressive strength for 1:1 cement to sand ratio

b) The values of compressive strengths for polymer-mortar for 1:2 cement to sand ratio (Fig. 9) vary between 70.1996MPa for specimen of 1:2 (40:60) and 101.663MPa for specimen of 1:1 (30:70), and the highest compression strength at specimen of 1:2 (30:70) it is 101.663 MPa.

This difference in both ratios is a result of the difference in percentages between sand and cement and the difference in proportions of polymer-mortar composite and the adhesion between them.

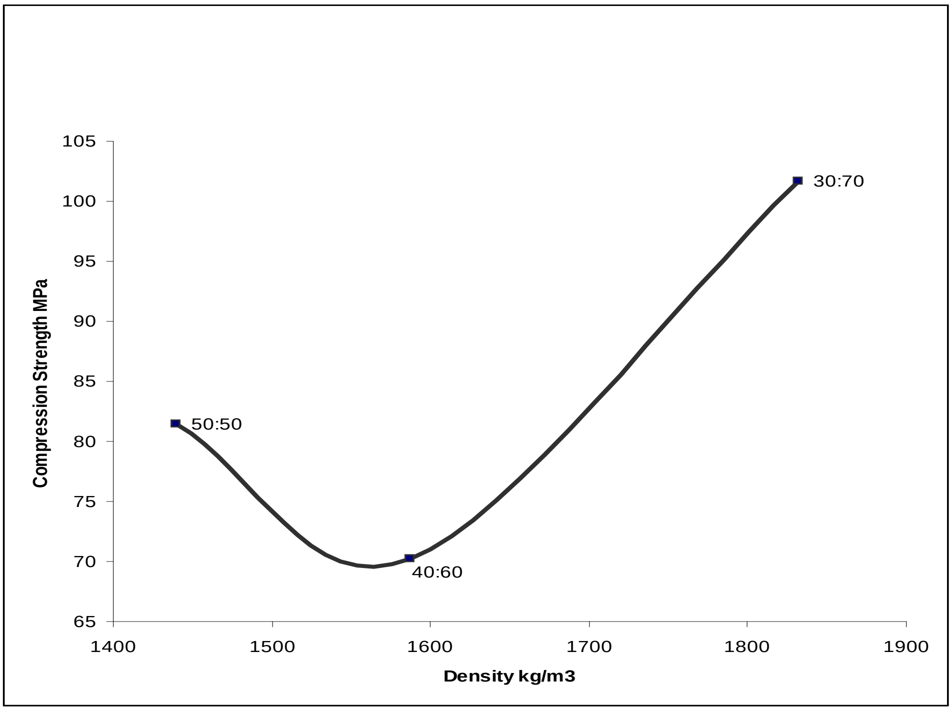


Fig.9. Compressive strength for 1:2 cement to sand ratio.

5.5 Flexural Strength Test

The following observations can be made from the experimental results:

a) The values of flexural strengths for polymer-mortar (Fig.10) vary between 48.6528MPa for specimen of 1:1 (50:50) and 57.648MPa for specimen of 1:1 (30:70), and the highest flexural strength at specimen of 1:1 (30:70) it is 57.648MPa.

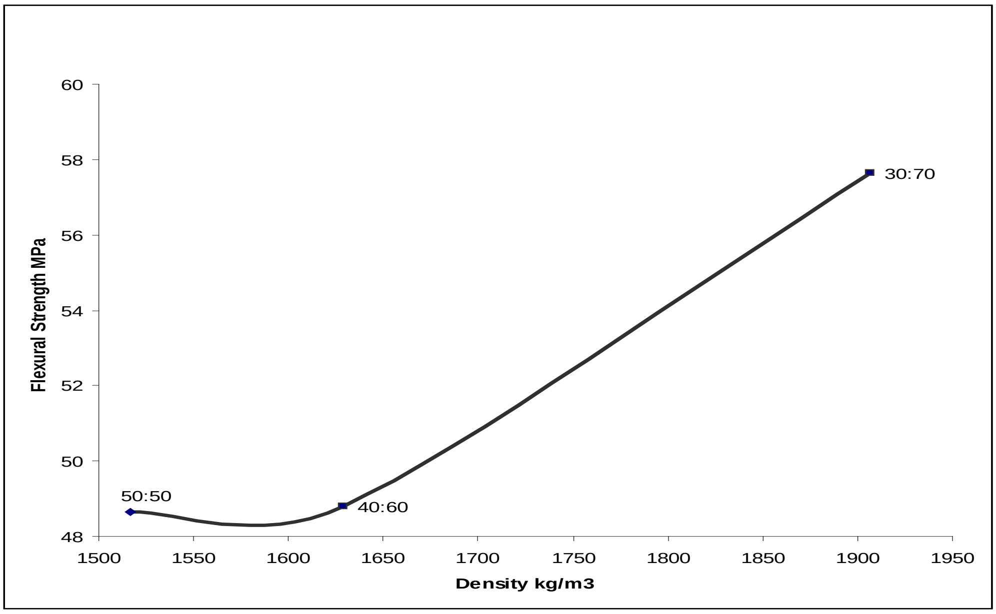


Fig.10. Flexural strength for 1:1 cement to sand ratio.

b) The values of flexural strengths for polymer-mortar for 1:2 cement to sand ratio (Fig. 11) vary between 43.1808MPa for specimen of 1:2 (50:50), and 60.5184MPa for specimen of 1:2 (30:70), and the highest flexural strength at specimen of 1:2 (30:70) it is 60.5184MPa.

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 density this may increase the adhesion strength. The polymer- mortar with 50:50 ratio showed a decrease in flexural strength, this is because of reducing in the bond strength between polymer and mortar particles and also the increment of liquid in the composite.

This difference in both ratios is a result of the difference in percentages between sand and cement and the difference in proportions of polymer-mortar composite and the adhesion between them.

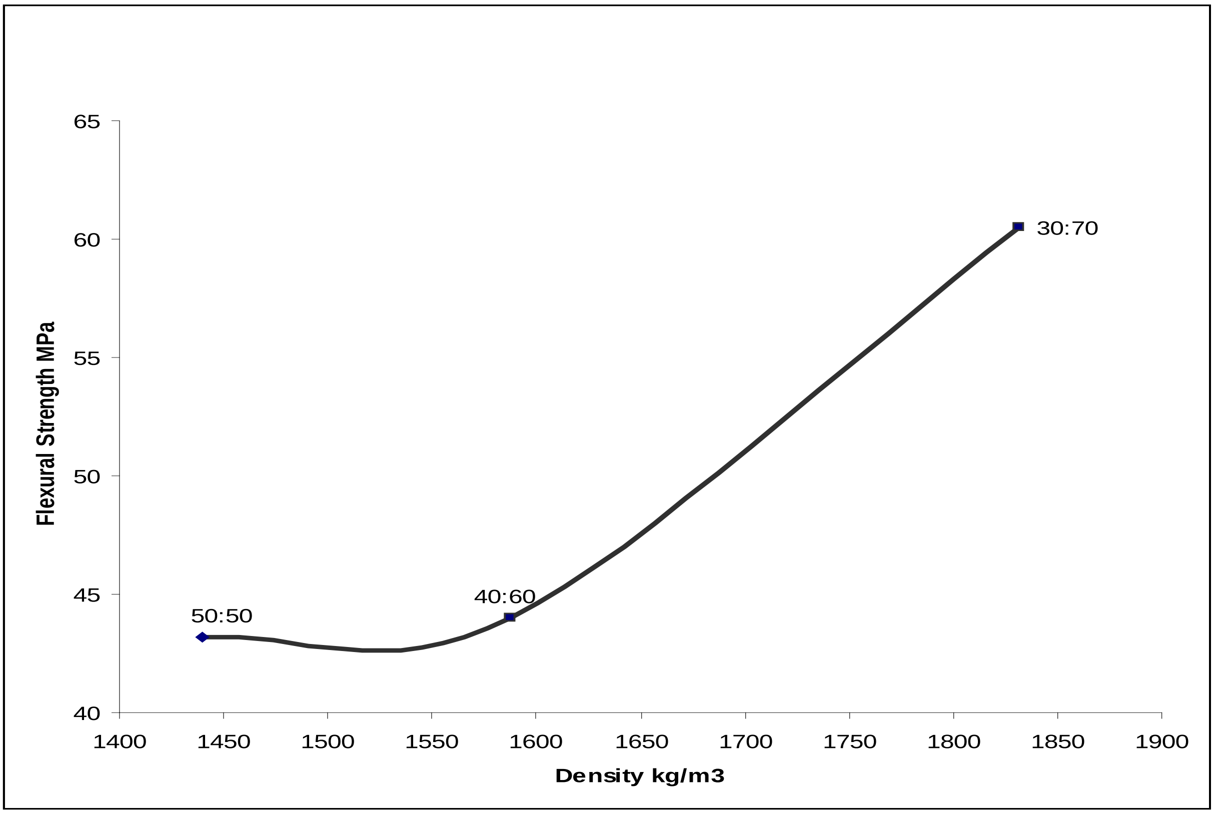


Fig.11. Flexural strength for 1:1 cement to sand ratio.

6. Conclusion

The following main conclusion were achieved from this study

i. The percentage of polymer that added to the mortar can affect the properties.

ii. The addition of polymer to mortar increases the tensile and flexural strength and reduces their brittle nature.

iii. The composite with 30:70 polymer-mortar ratio is the better ratio in mechanical properties as in compression and flexural.

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