Properties of Concrete Modified with Polymers And Factors affecting Concrete Polymer

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Abstract

The aim of this study is to find out the effect of different types of polymer materials, adding to the normal concrete with different dosage, the polymer materials have a significant effect on the both mechanical properties of hardened concrete and fresh state mix. As a general adding polymer materials increase the mechanical properties of concrete such as, compressive strength, tensile strength, flexural strength, modulus of elasticity and make a concrete more durable. Using polymers by different percent reduce the permeability of the mix to very low range, concrete modified with polymer has many advantage and desired properties, and because of these properties has many applications as construction materials in civil engineering field. In this study the summary of mechanical properties of different polymers are presented. Those factors affecting the polymer concrete are also discussed, the advantages and applications of polymer modified concrete (PMC) are mentioned. Using 10% of epoxy resin as additive to the concrete mix with a W/C = 0.4 improve the workability of the mix. Using 10% of epoxy resin increases the compressive strength of concrete to the 78 MPa. While using 15% of styrene butadiene rubber (SBR) and 10% polymer polyvinyl alcohol (PVA) also increase the compressive strength. Tensile strength and flexural strength are also increase by using different type of polymer each depending on the type of polymer and its dosage.

Keywords: Concrete polymer, Polymer modified concrete, Mechanical properties of PMC.

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1-2 General

Concretes and Portland cement are the most popular widely used construction materials in the world due to many desirable property; many various types concrete can be produced based on different type of cement [1]. Concrete as a proper construction material over all the world have many desirable properties, such as, high compressive strength, durable, high stiffness, low coast, ease of fabrication and use for the applications. These features are the main factors to be taken into account for any application. Nevertheless concrete as a construction material is not free from the shortage, the main shortcomings for the concrete are, low tensile strength, poor flexural strength, high porosity, permeability, brittleness, low strain capacity, freeze thaw deterioration, destruction by corrosive chemicals etc. [1]. These disadvantages are focused on as more and more accurately since we have become more and more concerned with save of energy and materials [2]. Many research and approach was used to improve the properties on concrete and modify the undesirable property to a desirable feature, using admixture, mechanical materials, different type of aggregates, different water cement ratio, superplasticizer, and other new techniques. Using different polymers material is a one of the many approach to enhance the mechanical properties of concrete and cement mortar.

Polymer concrete is a composite material which is mainly gained by combining various polymeric materials in fresh state of concrete mixtures. The polymerized monomer work as a binder for the aggregates and the resulting composite is called “Concrete.” [3]. Polymer concrete was come in the late of 1950s and became more famous in the 1970s. The integration of concrete with polymers enhances properties of concrete, giving excellent strength, durability and better flow properties [3]. Concluded, that polymer concrete become more popular due to its many desired properties. It is very strong, durable, high compressive strength, cures rapidly, high specific strength, and impedance to chemical materials, polymer concrete has found application in very specialized domains such as its use in reinforced slabs, overlays for highway pavements and floors bridge decks or pipe coatings, repair, and precast elements. At the same time the polymer material was used in machine construction when the vibration damping properties of polymer concrete materials was discovered [1, 4 and 5]. The beginning use of polymer concrete has been reported for building cladding. Afterward because of rapid curing, excellent bond to cement concrete and steel reinforcement, high strength, and durability; it was widely used as repair material [1, 3, and 4]. Most of repair and finishing materials that used in Japan are concretes and mortars modified with polymers, but concrete polymer is less used because of its high cost ration to performance, mortar modified with polymer is used more. But in the United States of America concrete polymer is widely used for coating bridges. The main and the only hindrance to use these types of materials are high cost, but at the same time the give a high properties. Like high durability and other, then they will not need maintenance a lot [3, 6].

Another application of concrete polymer in civil engineering filed is using polymer concrete for producing a various precast element, such as drains, tanks for chemical liquid, manholes, concrete barriers for highways and others [4, 6]. Another area which polymer concrete are needed to be use is a radiation shielding, gamma and neutron rays are the main types of radiation that should be take into account in the design of shield. Lately there are many requests for enhancing the properties of polymer concrete that come with a tough requirements like heat resistance, strength and others to be use such as shielding materials [1]. Reactions between polymers and cement particles in PCC have a great influence on their performance and they have been extensively studied in recent years, such as concrete with vinyl polymers, concrete with polyvinyl chloride, polystyrene, or phenolic resins. The properties of polymer-concrete are influenced by the chemical nature, the type, and the ratio used for the polymer [3]. Condition of preparation in polymer concrete has a main effect on the properties of concrete polymer, so the properties of concrete polymer vary depending on the condition of preparation. For a specific type of polymer concrete, the properties are strongly related to the binder content, properties of micro filler, curing condition, distribution size of aggregates and others [4]. Other factors that affect the properties of concrete polymer are the reaction between cement particles and polymer, which is has a great impact on the behavior of concrete polymer [3]. Recently the properties of many types of polymers are extensively studied, to producing a best concrete polymer. Such as concrete with unsaturated polyester resin, polyurethane resins, epoxy resins, furan resins, vinyl polymers, concrete with polyvinyl chloride, polystyrene, or phenolic resins and urea formaldehyde resin [3, 4]. The properties of polymer-concrete are mainly influenced by the chemical nature, the type, and the ratio used for the polymer [3]. As a general 75-80% concrete polymer volume are aggregates and fillers [4]. According to the data from literature, the annual production of cement is approximately 4,180 million meter cubic for year 2014.

If only a small portion of this is used to produce polymer concrete compounds, a good market for these materials results [1]. Many studies and research are implemented in the literature to observe properties of concrete that modified with different type of polymers are considered and discussed below, the effect of fiber reinforced and their effect on the polymer concrete are discussed.

1-3 Classification of Polymer-Concrete Materials:

According to the process of preparing the polymer concrete there are three main types of concrete polymers:

1-3-1 Polymer Portland cement concrete (PPCC):

A monomer, pre polymer of dispersed polymer is combined into a Portland cement mix and a polymer network formed in situ during curing of the concrete.

1-3-2 Polymer-Impregnated Concrete (PIC):

Before formed concrete is impregnated with a monomer which is thereafter polymerized in situ. Polymers improve the strength behavior of the original concrete.

1-3-3 Polymer Concrete (PC):

A polymer is used to link an aggregate together. It is also called Resin Concrete [7].

1-4 Advantages of Polymer Concrete:

The concrete modified with polymer has many desired property, below the main advantages are mentioned:

1- High compressive strength and high impact resistance.

2- Good resistance to abrasion and chemical attack.

3- High resistance against freezing and thawing.

4- Low permeability

5- High durability of hardened concrete

6- Good workability of fresh concrete.

7- Improving the bond characteristics between old and new concrete.

8- Enhancing tensile and flexural strength property.

9- Good vibration damping property.

10- Others.

1-5 Uses and applications of concrete modified with polymers:

Due the advantages that discussed before polymers concrete has a wide range use and applications as mentioned below:

1. Polymer modified concrete is used in flooring, water tanks, septic tanks, silos, swimming pools, drains, pipes, and ship decks.
2. Polymer modified concrete with combination with fiber reinforcing to improve tensile strength and reduced cracking.
3. Surface impregnation of bridge decks
4. Used as a repair material for the concrete structure and increase the life time of the old structures.
5. Due to its high resistance to the chemical attack, abrasion and high permeability, it is widely used in the underwater and marine appellations.
6. Application in hydraulic structures
7. Structural members: The polymer impregnated concrete have a great potential as a structural material. The polymer modified concrete represent significant enhancement over the conventional concrete.
8. The internal cracks and voids are the root cause behind all the problems in conventional concrete structure. As the polymer impregnation solves the root cause, it is best used in structural members.
9. Marine works
10. Prefabricated structural elements
11. Pre-stressed concrete
12. Nuclear power plants
13. Sewage works and desalination plants
14. Waterproofing of structures and numerous industrial applications [7, 8].

1-6 Common types of polymers that are used:

1. Urethanes: Urethanes are produced by the reaction of isocyanates with the polyols
2. Acrylics: These are esters of acrylic and methacrylic acids
3. Vinyl
4. Epoxies: These are type of synthetic fibers
5. Styrene Butadiene Resin (SBR)

1-7 Factors affecting the properties of concrete polymer:

Polymer concrete is obtained by mixing polymeric resin materials with aggregate mixture. Sometimes micro fillers are used to fill the voids that exist in aggregate mixture. Many types of polymeric resins are used to produce a polymer concrete such as, polyester resin, epoxy resin, methacrylate, vinyl ester resin, furan resins and others. Because of the low coast, high availability, and a good mechanical properties, unsaturated polyester resins type are the most generally used to produce the polymer concrete [9]. Methyl Methacrylate Monomer (MMA), because of its high flammability properties and bad odour has a limited application, but, however have good advantages like good workability and low temperature curability [10]. In the European countries furan resins have great applications. The main factors that effect on the choosing a particular type of a polymer resin, for producing a concrete polymers are, cost, desired properties, and chemical/weather resistance is needed. Generally due to the better mechanical properties epoxy resins polymer are more preferred than the polyester type, especially its durability and when subjected to severe environment. But its high cost becomes a barrier to be use more and more. Many study has been performed to investigate the properties of both epoxy and concrete polymer, in a comparative study shows that traditionally epoxy concrete has better properties than polyester concrete, but the feature of polyester concrete can improved by adding micro filler to the same level of epoxy concrete [11].

The resin potion reported by different researchers mostly lies in range of 10 to 20% by weight of concrete polymer. The compressive strength properties of polymer concrete are reported that depend on the dosage of resin in the mix [12]. Both compressive and flexural strength improve by increasing the dosage of polymer to the mix. After reaching the maximum value these properties either decrease or remain without change when more polymers content is increased. It is found out that both compressive strength and flexural strength gain maximum value when 14 to 16% of resin by weight is increased. Many studies in this area have been performed in the literature, and the variation of both compressive and flexure value of polymer concrete using different type and different potion of resin has been reported before [13]. Generally, it was observed that using 12% of resin potion for all types of resins gives the maximum strength. More content of resin is recommended when using fine aggregate, because of large surface area of the fine aggregate a strong bond will result [4]. Many studies has been performed in the literature using different types of aggregates, such as gravel, river sand, quartz, granite, and foundry sand. For producing the concrete polymer [4]. Using different types of fibers like, steel fiber, glass fiber, polyester fiber, carbon fiber by different quantities, for enhancing the properties of polymer concrete has been reported by various researchers. Most of researches have reported that adding 0 to 6% of glass fiber by weight to the concrete polymer enhance the post peak properties of polymer concrete. The micro filler is a fine powders which its particle size are less than 80 microns, often times micro filler is used in producing the concrete polymer which is has a grate action in filling the voids between the aggregate particles and increasing the strength of concrete polymer.

The common types of micro filler that has been used in the literature are calcium carbonate, fly ash and silica fume. Fly ash is the most used one because of its easy availability. And also its reported that using fly ash enhance the workability of fresh polymer concrete and give an excellent finish surface [4]. Many author reported that the addition of fly ash is not only enhance the workability of fresh concrete polymer mix, but also has a great effect on the improving the mechanical properties of polymer concrete. Improving the compressive strength up to 30% by adding 15% of fly ash has been achieved in the literature [4]. The performance of fly ash as a filler is much better than the performance of silica fume as a filler [4].

Another factor that has a significance influence on the properties of concrete polymer is the aggregate grading. The proportions of both coarse and fine aggregate should be in such way that aggregate mixture has maximum bulk density and minimum void content. This well gradation of aggregate mixture will minimize the amount of binder that need to achieve a best bonding between all the aggregate particles. Generally, the binder content rangers vary from 5% to 15% of the total weight, but if the fine aggregate was used, may need up to 20% binder. Silane is an inorganic compound has been extensively used for as coupling agent for fibers; when the fiber is treated with silane agent the tensile strength of the mix improve significantly [4]. Table.1 below shows the details of the various types of fiber reinforcements and their effect on the properties of polymer concrete as reported by various researchers.

Table 1- Fiber reinforcement and their effect on the polymer concrete [4]

Author	Resin	Aggregate	Fibers addition	Properties evaluated	Brief findings
Broniewski et al. [14] cited in [4]	Epoxy resin	Sand	Steel fibers of 0.24 mm Diameter and 15 mm length, added in 0 to 3.5% by weight	Flexural strength, creep	Addition of 3.5% steel fibers increases the flexural strength by 40%.
Valore and Naus [15] cited in [4]	Polyester, vinyl ester, epoxy	-	Nylon, glass, aramid, steel fibers of length 12.7 to 38.1 mm	Compressive strength, young's modulus, split tensile strength, and density	(i) Compressive strength increases as function of density. (ii) Flexural strength is related to compressive strength (in Psi) as $f_f = 25\sqrt{f_c} psi$ (iii) Fiber addition increases flexural strength and ductility. (iv) Longer fibers have better effect on compressive strength.
Brocken brough [16] cited in [4]	Mrthacrylate	-	(i)steel fibers of 0.4 mm diameter, 1-3% (ii) Glass fibers of 12.7 mm length, 1-3%	Compressive strength, flexural strength, and split tensile strength	(i) Addition of steel fibers increases the compressive strength, whereas the addition of glass fibers deceases the compressive strength. (ii) Flexural strength of polymer concrete is observed to increase by addition of both steel and glass fibers.
Vipulanandan et al. [17] cited in [4]	(i) Epoxy (ii) Polyester	Ottawa sand, blasting sand	Glass fibers, 0-4%	Compressive strength, flexural strength, and split tensile strength	(i) Maximum compressive and flexural strength are reported at 14% resin content. (ii) Addition of glass fibers increases the flexural strength, compressive strength. (iii) Silane treatment increases the flexural strength by 25%.
Vipulanandan and Mebarkia [18] cited in [4]	Polyester	Blasting sand	Glass fibers, 0-6%	Flexural strength	(I) Flexural strength increases with increases in resin content. (ii) Addition of glass fibers is reported to enhance the strength and toughness of polymer concrete. (iii) Silane treatment of aggregate and fibers also enhanced the flexural strength.
Mebarkia and Vipulanandan [19] cited in [4]	Polyester	Blasting sand	Glass fibers of 13 mm length, 0-6%	Compressive strength	(i) For 18% resin and 4% glass fiber content, an increase of 33% in compressive strength was reported over unreinforced polymer concrete. (ii) Flexural strain and toughness increase with addition of fibers.

Rebeiz [20] cited in [4]	Polyester	Gravel, dried sand	Steel fibers of 0.5 mm diameter and 30 mm length, 0-2% by weight	Compressive strength	(i) An optimum mix having 10% resin, 45% gravel, 32% dried sand and 13% fly ash was reported. (ii) Polymer concrete archives around 80% of the 28-day strength in on day. (iii) Addition of steel fibers beyond 1.3% increases the compressive strength of the specimens from 80 MPa to 100 MPa. (iv) Steel fibers also increase the ductility of the polymer concrete which results in a better post peak behavior.
Sett and Vipulanandan [21] cited in [4]	Polyester	Blasting sand	Glass fibers and carbon fibers, 0-6% by weight	Compressive strength, tensile strength, and damping ratio	(i) Compressive strength and the failure strain are reported to increase by 40% by addition of 6% of glass fibers. (ii) Carbon fibers do not have any significant effect on the compressive properties. (iii) It was further observed that damping ratio of polymer concrete increased with addition of glass fibers and carbon fibers.
Laredo Dos Reis [22] cited in [4]	Epoxy	Foundry sand	Glass fibers & carbon fibers, 0-2% by weight	Compressive strength	(i) Addition of fibers increases the compressive strength by 27% for glass fibers and 36-55% increase for carbon fibers. (ii) Ductility of polymer concrete improved with addition of fibers.
Jo et al. [23] cited in [4]	polyester	Pea gravel and siliceous river sand	Nano-MMT particles	Flexural strength, split tensile strength	(i) Polymer concrete mix was obtained using 11% resin content, 45% coarse aggregates, 35% fine aggregates, and 11% $CaCO_3$ (ii) It was found that flexural strength and split tensile strength increase with addition of nanoparticles.
Xu and Yu [24] cited in [4]	Polyester	Granite	Copper coated stainless steel fibers, *L/d* ratio of 70	Compressive strength	(i) Addition of steel fibers improves the properties of polymer concrete. (ii) Compressive strength of steel fiber reinforced polymer concrete is higher than that of plain polymer concrete.
Bai et al. [25] cited in [4]	Epoxy resin	Granite	Glass fibers of 5-25 mm length, added 1 to 5% by weight	Damping	(i) Granite mix is the most important parameter controlling the damping. (ii) Highest damping is reported for mix containing 16% epoxy resin, 5% glass fibers, and granite mix having high proportion of fine aggregate.

2- Concrete Polymer Properties:

2-1 Fresh Concrete Properties:

A study was performed to investigate the properties of concrete modified with different polymer materials, at fresh and hardened state. Three different type of polymer was used: polyurethane, epoxy resins, and methylcellulose at different proportions and different water cement ratio. The main aim of this test was to enhance the workability and rheological properties of the mix and also mechanical properties of the hard concrete.

Some sample was prepared with different water cement ration, and slump test was carried out for each sample, the result of the slum test summarized in the Table 2 below:

Table 2: Slump test for ordinary cement concrete

Water/cement ratio	Slump, mm
0.5	34
0.47	31
0.45	18
0.43	6
0.4	4.5

From the above results we derive both samples with water cement ratio w/c = 0.4 and 0.43 cannot be included in any class of workability, which shows a very low workability. So, we choose the sample of the concrete with a water/cement ration 0.4 as a standard sample the three different type of polymer as mentioned before was added to the mix in different proportions to investigate the effect of each polymer and its percentage on the workability properties of the mix.

The addition of polymer materials as below:

1- Polyurethane - 10% by weight of cement.

2- Epoxy resin - 1%, 5% and 10% by weight of cement.

3- Methylcellulose - 0.2% and 0.6% by weight of cement.

After adding the polymer material with these different properties the slump test was carried out to find out the workability properties of each sample and the effect of each type of polymers. The result of the test summarized in the Table 3 below.

Table 3: Slump test for polymer cement concrete with water/cement ratio = 0.4

Mixtures	The additives Proportion	Slump for PMC with w/c ratio = 0.4
PMC with epoxy	1%	5 mm
PMC with epoxy	5%	8 mm
PMC with epoxy	10%	67 mm
PMC with Methylcellulose	0.2%	36 mm
PMC with Methylcellulose	0.6%	58 mm
PMC with Polyurethane	10%	7 mm

The test result shows that adding epoxy resin to the mix with a proportion less than 5% do not enhance the workability and also the adding the polyurethane with 10% do not improve the workability and it is not recommended to be use for concrete mixture. And the graph below shows the graphical value of each slump test [3].

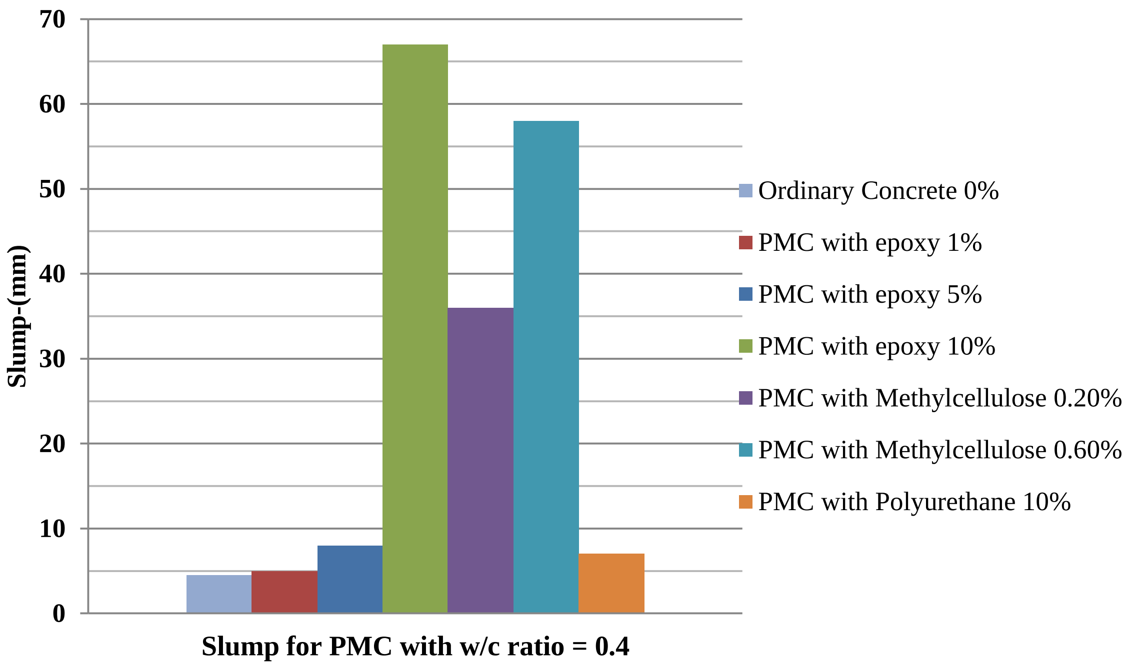

Figure 1- Slump test result for concrete modified with polymers

The graph shows that the epoxy resin with 10% has the best influnce on improving the workability, at a second level methylcellulose with 0.6% have a good effect on the improving the workability of the mix. And the third level methylcellulose with 0.2% has a less effect on the workability compared with other results. And the concrete mix containing epoxy resin with 10% does not need a long time vibration and it can be cast to any complex shape [3].

2-2 Mechanical Properties:

2-2-1 Compressive Strength:

The influence of different type of polymer materials on the improving the mechanical strength of the mix modified with polymer is discussed, the proportion same as that prepared for the workability test with same water cement ration 0.4. Table.4 below shows the compressive strength test result for the control sample without polymer materials and with a water cement ratio 0.4, for 1, 3, 7 and 28 days of curing. And the result for the others sample modified with the polymers is also shown [3].

Table 4: Compressive strength test result for different concrete modified with polymer

Mixture, w/c ratio	1 Day (Map)	3 Days (MPa)	7 Days (MPa)	28 Days (MPa)
Ordinary Concrete, w/c = 0.4	**17.32**	**31.50**	**26.60**	**42.00**
	18.26	27.10	38.00	47.20
	19.28	34.10	45.40	46.90
	20.4	35.80	42.20	47.80
	17.86	33.20	44.20	45.80
	16.54	36.70	42.00	43.90
PMC with 1% Epoxy resin. w/c = 0.4	**16.32**	**31.80**	**26.60**	**42.00**
	17.28	25.10	38.00	46.20
	19.28	34.10	39.40	40.90
	18.4	35.80	38.20	44.80
	17.86	33.20	34.20	52.08
	16.54	36.70	42.00	44.20
PMC with 5% Epoxy resin, w/c = 0.4	**16.18**	**31.70**	**40.92**	**50.00**
	17.92	36.00	44.48	52.30
	18.51	35.20	39.88	56.00
	16.41	36.40	42.68	55.40
	17.63	27.40	42.36	56.40
	17.99	27.30	44.12	56.30
PMC with 10% Epoxy resin, w/c = 0,4	**12.97**	**31.50**	**54.48**	**75.20**
	13.22	28.80	49.90	78.20
	13.66	29.80	48.8	74.50
	12.99	28.20	57.70	76.20
	12.60	29.40	47.50	77.60
	12.96	29.40	56.80	75.20
PMC with 0.6% Methylcellulose, w/c = 0.4	**11.52**	**27.90**	**28.60**	**33.40**
	10.65	28.50	32.20	48.90
	10.54	27.60	34.50	49.50
	10.90	26.30	36.20	50.20
	10.60	28.40	33.50	48.70
	9.99	26.60	36.40	51.40
PMC with 0.2% Methylcellulose, w/c = 0.4	**12.34**	**27.80**	**27.30**	**43.40**
	11.26	26.50	35.20	38.50
	10.54	29.60	36.20	49.50
	9.95	28.30	32.90	49.20
	11.40	25.40	35.50	50.70
	9.89	29.60	36.90	50.80
PMC with 10% Polyurethane, w/c = 0.4	**60.80**	**17.90**	**22.50**	**39.50**
	12.65	16.50	24.60	40.20
	10.90	14.60	19.80	35.60
	11.00	19.80	25.60	42.50
	7.90	20.00	22.30	42.90
	8.50	19.70	23.50	42.10

From the test result we can note that the compressive strength for control sample is increase day after day with the time. And also we can note that the compressive strength is small for this mix with a water cement ratio 0.4 because with this water cement ration we cannot make a good and proper compaction for the mix.

The compressive strength also carried out for the others mix modified with different percent of polymers, and the compressive strength at different age of curing was recorded. The largest value compressive strength of control sample at 28 days was 47.8 MPa. And the maximum compressive strength of concrete modified with epoxy resin with 1% for same water cement ratio was 52.08 MPa which is approximately equal to the standard sample.

So, we can say there is no a significant improvement in compressive strength with this percentage of the resin. By increasing the percentage of the epoxy resin from 1% to 5% the compressive strength was increased during the time and the maximum value at 28 days of curing was 56.4 MPa. And this improvement in strength is not adequate strength that classifies a mix as a high performance concrete.

But the best result was achieved when the 10% of epoxy resin was used which is the maximum value of compressive strength at 28 days was 78.2 MPa this strength is adequate to transfer the concrete class to high performance concrete class. The other types of resin they don’t have a significant effect on the improving the compressive strength as shown in the Figure.2 below. The figure represent the compressive strength of concrete modified with polymers at different age of curing foe each day six sample was tested and the average of the six sample plotted below [3].

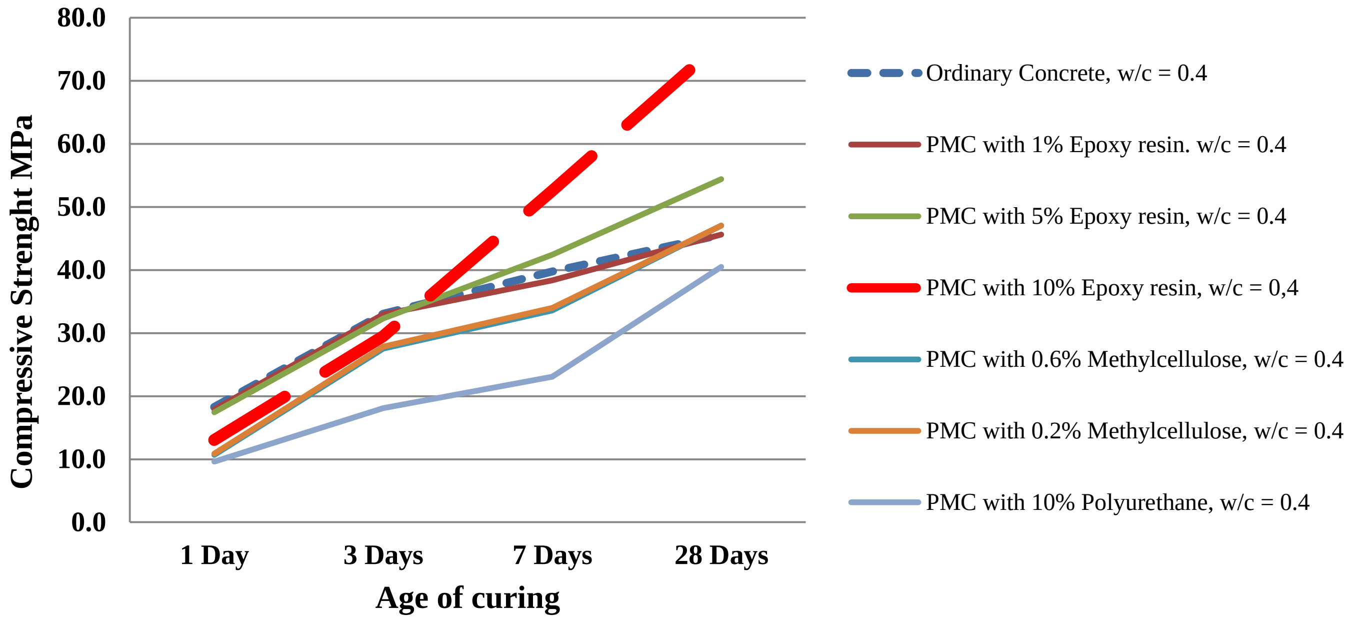

Figure 2- Compressive strength of concrete modified with polymers for different day of curing, average of six samples for each age of curing.

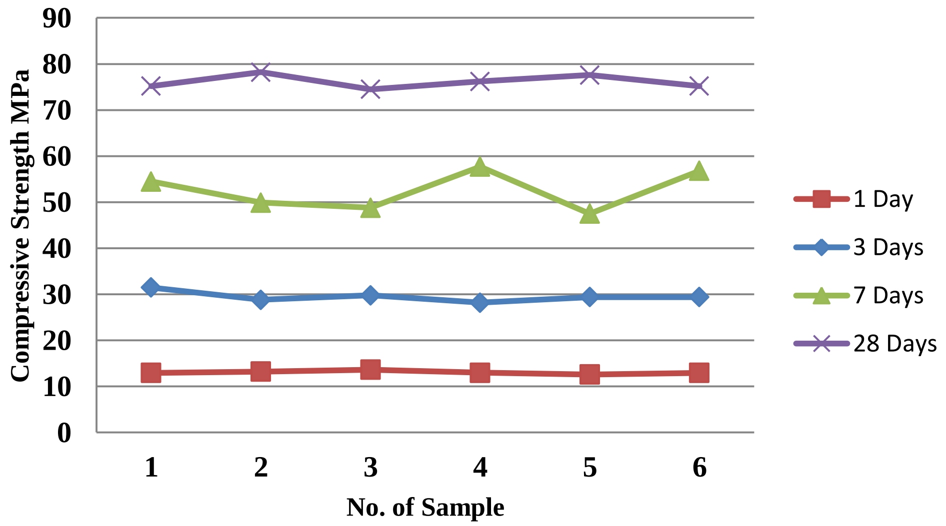

Figure 3- Compressive Strength of PMC with 10% Epoxy resin

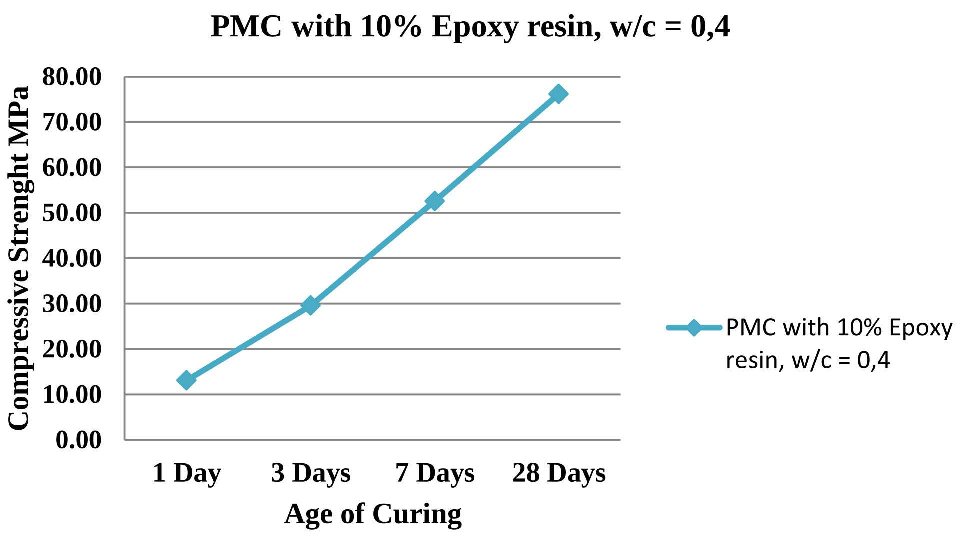

Figure 4- Compressive Strength of PMC with 10% Epoxy resin

Another study was performed in the literature which is concrete modified with two different types of polymers and their effect on the compressive strength of concrete was investigated. The first one polymer polyvinyl alcohol (PVA) and the second one was styrene-butadiene rubber (SBR) the polymers was dissolved in water with different portion from 2% to 20% and the effect of each percent on the compressive strength was recorded at 28 days of curing.

Figure.5 below show the test result of the compressive strength test for both mixtures modified with PVA and SBR. In the case using SBR from the graph can be note that there is a rapid increase in compressive strength when the percentage of SBR was increased from 5% to the 15%. And reaching it is maximum value at 28 days of curing with 15%. This represent that the polymers acts as binder between raw materials when they mixing together. When more additives added to the mix a stronger bond exist and this produce a higher strength. But increasing the polymer content to 20% will reduce the compressive strength. The second graph show the test result when PVA was used different percentage, the graph show that the maximum strength was obtained when 10% of PVA was used. By comparing the two graph we note that the effect of SBR on the compressive strength higher than the effect of PVA. [5].

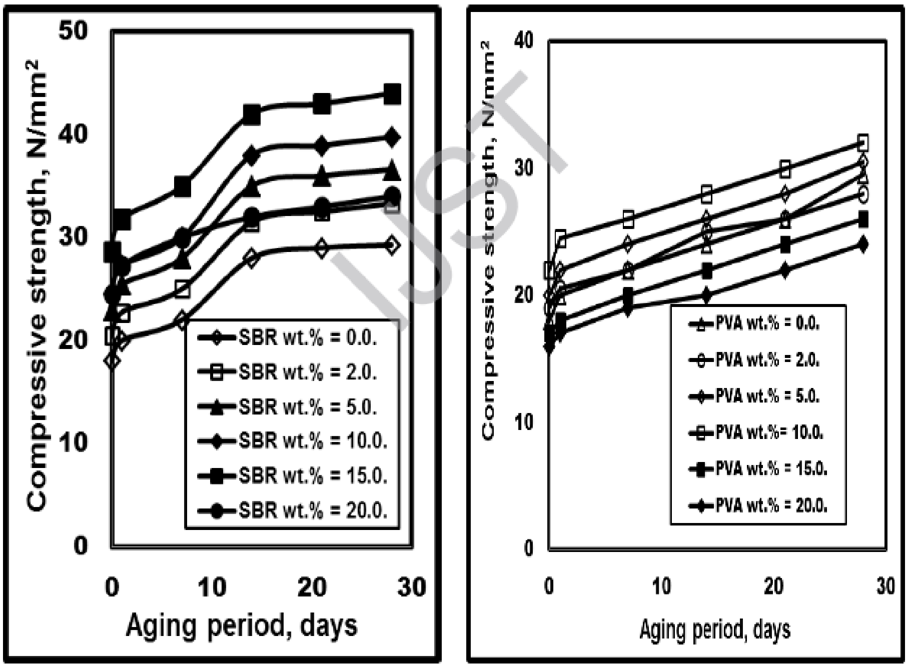

Figure 5- Effect of SBR and PVA concentrations on concrete compressive strenght at water/cement = 0.46

2-2-2 Flexural Strenght:

The flexural strength test result are summarized in the Table 5 below, And also the result of the test presented in the Figure.6. It can be note that the polymer concrete has a greater value of resistance to flexure than the concrete without polymer. The polymer materials have the ability to make flexible points between concrete ingredients. As predicted the maximum value of flexure strength was gained when the epoxy resin was used, this because of a specific ability to form elastic bridges between concrete components. The test was performed at different ages 7days and 28 days, and the maximum value was 27.96 MPa at 28 days when 10% of epoxy resin was used [3].

Table 5 : The flexural strenght test result of concrete

Type of concrete	The additives proportion (%)	Flexural strength (MPa)	
		7 days	28 days
PMC with epoxy	1	3.7	16.8
	5	4.5	22.45
	10	7.2	27.96
PMC with Methylcellulose	0.6	2.9	23.56
	0.2	5.7	22.23
PMC with Polyurethane	10	3.6	17.4
Ordinary concrete	0	3.0	15.9

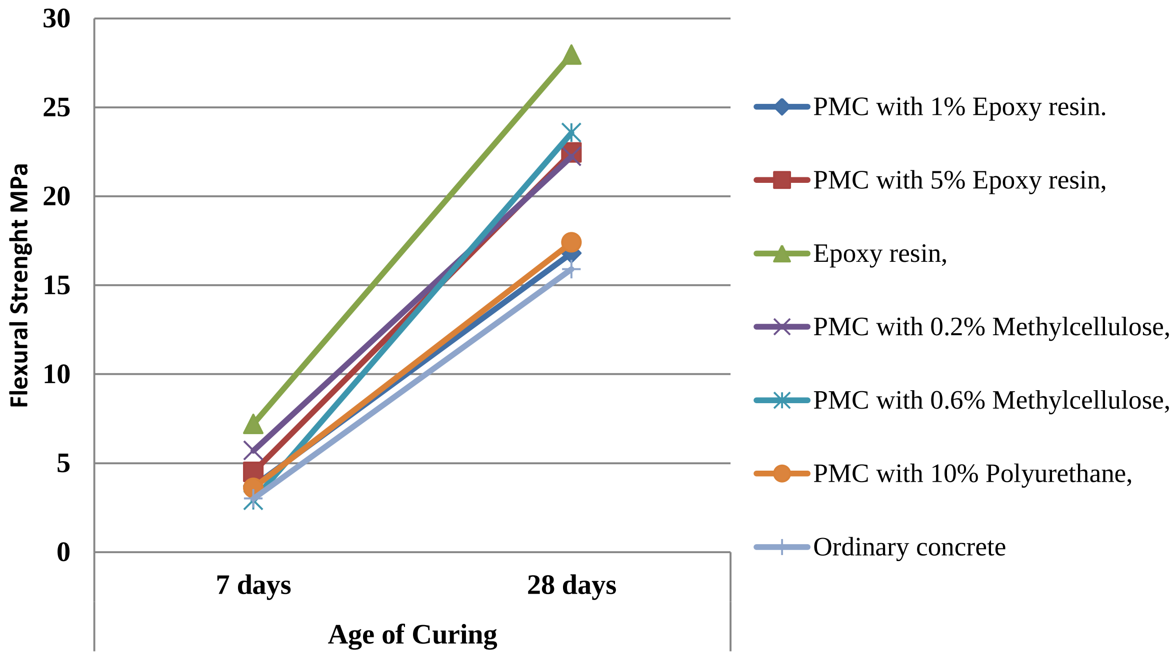

Figure 6- Flexural Strength of PMC at different age

Figures below show the microstructure of standard sample and also concrete modified with polymers. Figure.7 shows the ordinary concrete which we can see the products of hydration overgrown and how they include the aggregate particles. No elastic formation is observed, but the way in which the new hydration products cover both aggregate and cement particle.

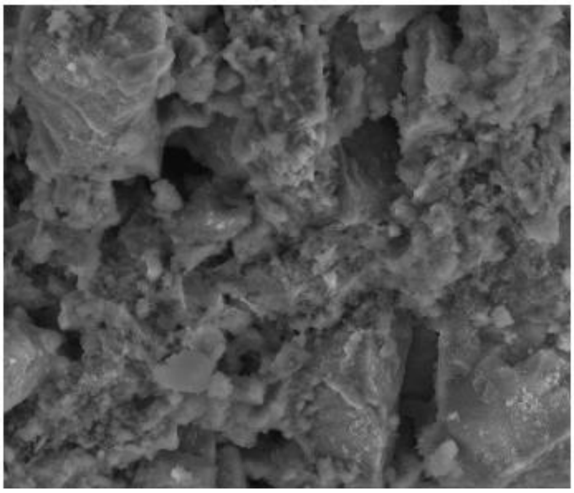

Figure 7 - Ordinary Concrete (5000X)

Figure.8 shows a structure of concrete mixture modified with epoxy resin. As it is appear the structure is more uniform and epoxy resin tends to build elastic bridges between concrete ingredients, which are lead to increase mechanical strength. Due to the ability of polymer material that creates a thin layer to cement particle surface, products of hydration are less developed. And this cause delay hydration reactions. When polymerization starts, the polymer is placed between particles, especially improving the flexural strength of the material.

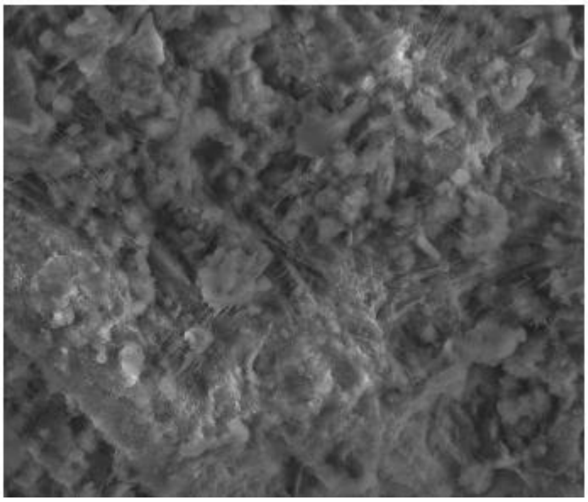

Figure 8- PCC with epoxy (5000X)

Figure.9 shows the structure of a concrete composition with methylcellulose. Because it tends to involve air with foam formed in addition, the material becomes more porous, weak points appear in the structure, while the tendency of methylcellulose is to polymerize inside these holes, but without filling them completely.

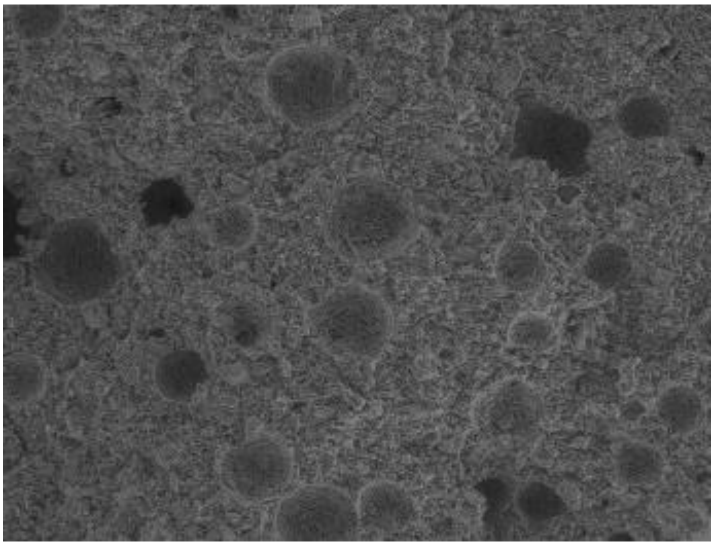

Figure 9- PCC with methylcellulose, (mag 300X)

Figure.10 shows the microstructures of mixtures containing polyurethane. In these mixtures, it can be note that a large number of air voids are exist. Polyurethane tends, like methylcellulose, to polymerize inside these goals. All microstructures test were performed at 28 days of hydration.

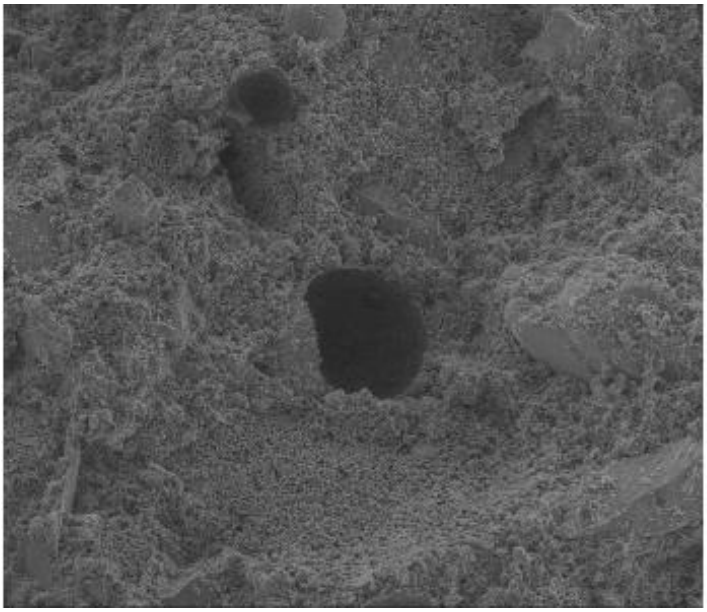

Figure 10- PCC with polyurethane, mag (300X)

2-2-3 Tensile Strength:

Test performed to find out the effect of PVA and SBR on the tensile strength. Figure.11 below shows test result for both concrete mixes modified with polymer materials with different percentages. From the graphs is clear that when the percent of polymer increase the splitting tensile strength was increased for both type of polymers. In the case of SBR the maximum values of strength was obtained when 15% was used. And in the case of PVA by using 10% the maximum value was achieved. Because of its smooth and smaller particle PVA reaches its optimum condition vastly than the SBR, but at the same time it has lower tensile strength compared to SBR and this due to its slower absorption of water [5].

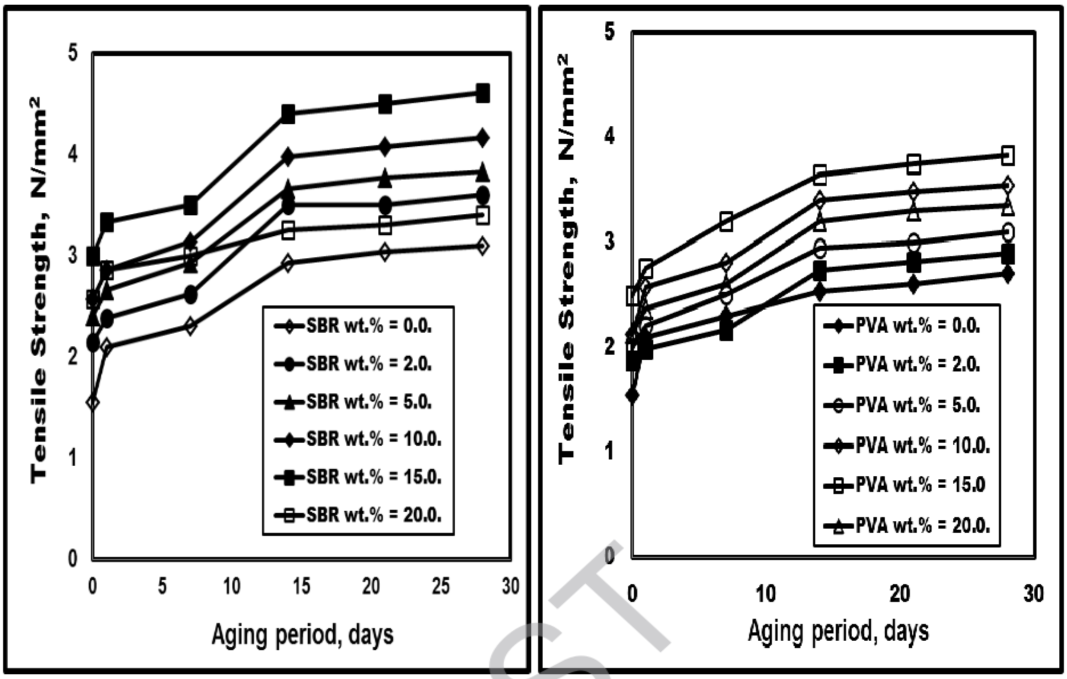

Figure 11- Effect of SBR and PVA on concrete tensile strength

2-2-4 Bond Strength:

A study performed to find out the effect of both SBR latex and Acrylic polymers materials on the bond strength properties. The mix modified by different percent of SBR and Acrylic which is 5%, 10% and 15%. The test shows that bond strength was higher at 10% polymer dosage for both of type [26].

2-2-5 Permeability

Polymer modified fiber reinforced concrete have an organization where the larger pores can be filled with polymers or sealed with continuous polymer films. By increasing the polymer to cement ratio the effect of filling or sealing pores is increases. When an Acrylic modified fiber reinforced concrete use the result shows a reduction in 60% permeability whereas SBR modified fiber reinforced concrete showed a 58.6% drop in permeability at 15% polymer dosage [26].

Table.6 below shows the mechanical properties of concrete modified with polymer, using different type of polymer, aggregate, and different properties are summarized.

Table 6- Summary of Mechanical Properties of Polymer Concrete [4]

Author	Resin	Aggregate and micro filler used	Variables	Properties evaluated	Brief findings
Okada et al. [27] cited in [4]	Polyester	Crushed stone, river sand, and calcium carbonate	Compressive strength, flexural strength, and so forth Resin, 10-15%; Filler, 10-15%; Temperature of test, 5 to 60°	Compressive strength, tensile strength	Compressive strength and tensile strength decrease with temperature.
Kobayashi and Ito [28] cited in [4]	Polyester	Crushed stone, fine sand	Silane treatment, resin content, 9 to 13%	Compressive strength, compressive fatigue	(i)Resin content does not have much effect on compressive strength. (ii)Temperature rise was observes for frequency range of 200-400Hz. (iii)Addition of 1% silane agent increases the load for withstanding 2 million cycles from 59% to 60% of ultimate strength.
Mani et al [11]	Epoxy polyester	Crushed quartzite, siliceous sand, and calcium carbonate	Resin type, silane treatment, and micro filler addition	Compressive strength, flexural, and split tensile strength	(i)Epoxy concrete has much superior properties than the polyester concrete. (ii)Compressive strength goes up by 30% for the polyester concrete and 36% for the epoxy concrete by incorporation for a silane coupling agent. (iii)The compressive and flexural strengths of the polyester concrete are greatly improved on incorporation of the micro filler.
Vipulanandan and Dharmarajan [12]	polyester	Ottawa sand	Temperature, strain rate, void content method of preparation, and resin content	Compressive strength, flexural strength	(i)Maximum flexural and compression modulus are observed between 14 and 16% resin content by weight. (ii)Strain rate was found to have very limited effect on the flexural behavior. (iii)Compaction molding was found to have better results than vibration molding.

Vipulanandan et al. [29] cited in [4]	Epoxy polyester	Ottawa sand, blasting sand	Resin content, silane treatment, compaction, and glass fiber content	Compressive strength, flexural, and split tensile strength	(i)Maximum compressive flexural strength were reported at 14%resin content. (ii)Addition of glass fibers increases the flexural strength compressive strength. (iii)Silane treatment increases the flexural strength by 25%.
Vipulanandan and paul. [30] cited in [4]	(i)Epoxy (ii)polyester	Ottawa sand, blasting sand	Temperature, strain rate, aggregate type, and curing conditions	Compressive strength, split tensile strength	(i)Compressive strength increases with curing temperature. (ii)Maximum strength was obtained for one-day room temperature curing followed by one-day curing at 80° C. (iii)Use of gap graded aggregate resulted in highest compressive strength.
Vipulanandan and paul. [31] cited in [4]	Polyester	Ottawa sand	Curing conditions silane treatment, and rate of loading	Compressive strength, tensile strength, and stress strain relationship	(i) Maximum compressive strength was obtained for a resin content of 15%. (ii) 1-day room temperature curing followed by 1-day curing at 80° C increased the compressive strength by around 50% as compared to 2-day curing at room temperature. (iii) Compressive strength and modulus increase with increase in strain rate. (iv)Silane treatment of aggregate increases the compressive strength by around 14%.
Vipulanandan and Chaturvedi . [32] cited in [4]	Polyester	Granite aggregate confirming to ASTM mesh No-5_50,river sand, and fly ash	Fly ash and river sand contents have been varied in full range of 0_100%of fine aggregate to study the replacement of river sand with fly ash	Flexural strength	(i)Fine aggregates in combination with fly ash and river sand show synergism in strength behavior and resistance to water absorption up to the level of 75% by weight of fly ash. (ii)At the higher level of fly ash, properties decline as the mix becomes unworkable due to the fact that pure fly ash, because of large surface area does not mix with resin binder effectively.
Maksimov et al. [33] cited in [4]	Polyester	58% crushed granite, 21% sand, and 10.4% calcium carbonate		Compressive strength, flexural strength	Compressive strength in the range of 90_108MPa has been reported.

Abdel-Fatah and El-Hawary [13]	Epoxy, polyester	56% Coarse aggregate and 36% fine aggregate	Resin content	Compressive strength, flexural strength	(i)Maximum compressive strength was achieved at 12% resin content for all types of resins. (ii)Highest modulus of rupture was also obtained at 12%resin content, which was almost 3 times that of cement concrete.
Ferreira [34] cited in [4]	Polyester	Clean sand, foundry sand, and $CaCO_3$	Resin content, micro filler content, mixing method, and type of sand	Three-point bend tests on specimens of 40×40×160mm	(i)Best results were obtained for 20% resin content. (ii)Clean sand gives better properties with low resin content as foundry sand has high specific surface.
Ribeiro et al.[35] cited in [4]	Epoxy, polyester	Clean sand, foundry sand, and $CaCO_3$	Resin content, micro filler content, type of sand, and curing cycle (7 day at 23°C and 3 hrs at 80°C)	Three-point bend tests on specimens of 40×40×160mm	(i)Curing cycle 3 hrs at 80°C gives almost the same result as 7 days at 23°C curing. (ii)Epoxy resin gives better properties with foundry sand as aggregate, whereas polyester gives better properties with clean sand because of the higher capacity of epoxy to wet the aggregates.
Rebeiz et al. [36] cited in [4]	Polyester	Pea gravel as coarse aggregate and sand as fine aggregate, fly ash	Fly ash content	compressive strength	(i)Replacing 15% by weight of sand with fly ash result in 30% increase in compressive strength. (ii)Caution should; however, be exercised when using a relatively high loading of fly ash, because the high surface area of the material would make the mix become too sticky and thus unworkable.
Barbuta and Lepadatu [37] cited in [4]	Epoxy	River gravel of 0-4 mm size and 4-8 mm size, silica fume (SUF)	Resin content, micro filler content	Compressive strength, flexural strength , and split tensile strength	(i) Compressive strength varies from 43.4 to 65.3 MPa and flexural strength varies from 12.29 to 17.5 MPa. (ii)Resin content of 15.6% was found suitable for almost all the properties of polymer concrete.
Haidar et al. [38] cited in [4]	Epoxy	Gravel of 2-4 mm, gravel to sand ratio of 0.25 used for optimum packing density	Resin content, curing conditions	Compressive strength, flexural strength	(i)Maximum compressive strength and flexural strength were reported for a resin content of 13%. (ii) Maximum compressive and flexural strength were obtained after 3 days of curing.

Mix proportions					
Ohama [39] cited in [4]	Polyester	Andesite, river sand, and calcium carbonate	Mix composition based upon maximum bulk density, curing conditions, and water content of aggregates	Compressive strength	(i)The following optimum mix proportion has been suggested: 11.25% resin, 11.25% calcium carbonate, 29.1% andesite (5-20mm), 9.6% sand (1.2-5mm), 38.8% sand (<1.2mm). (ii) Compressive strength becomes constant after 7-days curing at 20° C. (iii) Strength reduces with increases in water content of aggregate; maximum water content shall be limited to 0.1%.
Kim Et al. [40] cited in [4]	Epoxy resin	Sand >mesh no.6 and pebble <mesh no.6	Compaction ratio, size of aggregates, and mix composition	Damping factor, and modulus, and Compressive strength	An optimum mix was reported as shaving 50% pebble, 42% sand, and 75% resin.
Rebeiz [41] cited in [4]	Polyester resin From PET waste	Pea gravel, river sand, and fly ash	Curing time	Compressive strength, flexural strength	(i)Authors proposed an optimize mix based upon their study as that containing 10% resin, 45% pea gravel, 32% sand, and 13% fly ash. (ii)Polymer concrete achieves 80% of its strength after curing of one day, when compared to seven-day curing period.
Damping					
Suh and lee [42] cited in [4]	Polyester resin	Sand and gravel	Mix composition	Damping	(i)The polymer concrete bed had large damping factors over wide frequency range. (ii)Damping factor found experimentally were higher than those for steel structure and cast iron.
Cortes and Castillo [43] cited in [4]	Epoxy resin	Basalt, quartzite, up to 10 mm size	Test frequency	Damping, compared with that of cast iron	(i)Damping loss factor of polymer concrete is 65% higher than that of cast iron. (ii) Polymer concrete maintains its damping over a large frequency range.

Bignozzi et al. [44] cited in [4]	Polyester	Silica sand, calcium carbonate	Use of recycled fillers, that is powdered rubber, tyre rubber, and so forth	Damping, loss modulus	(i)Addition of powered rubber, tyre rubber, and so forth increases damping over wide temperature. (ii) Polymer concrete containing organic fillers can be used for making machine tool bases.
Orak [45] cited in [4]	Polyester	Quartz, 0.5mm-8mm	Mix composition	Damping factor	(i)Damping for polyester concrete is four to seven times higher than that of cast iron. (ii)Damping characteristics were not much influenced by mix composition.

Conclusions

The main conclusions of the study are:

1- Polymer materials improve the mechanical properties of hardened concrete and fresh properties of the mix.

2- Polymer materials improve the permeability properties of the concrete.

3- Using 10% of epoxy resin as additive to the concrete with a water/cement = 0.4 improve the workability of the fresh mix and increase the compressive strength of hardened concrete up to 78 MPa.

4- Tensile and flexural strength increase by using different types if polymer with different dosage.

5- Epoxy resins polymer are more preferred than the polyester type, especially because of its durability properties and when subjected to sever environments.

6- Micro filler materials have significant effect on the properties of concrete modified with polymer.

7- The most used resin dosage lies in range of 10% to 20% by weight of polymer concrete.

8- After reaching the maximum value of compressive strength and other properties adding more content of polymer will not cause any change in the values.

9- Addition 3.5% of steel fiber increases the flexural strength by 40% of concrete polymer.

10- Addition of steel fiber increases the compressive strength of concrete polymer while adding the glass fiber reduces the compressive strength.

11- Flexural strength of polymer concrete is observed to increase by addition of both steel and glass fibers.

References

[1] Gencel, O., Brostow, W., Martinez-Barrera, G., & Gok, M. S. (2012). Mechanical properties of polymer concretes containing different amount of hematite or colemanite. Polimery, 57(4).

[2] Jamshidi, M., Pakravan, H. R., & Pourkhorshidi, A. R. (2014). Application of polymer admixtures to modify concrete properties: effects of polymer type and content.

[3] Ion, I., Barroso Aguiar, J., Angelescu, N., & Stanciu, D. (2013). Properties of polymer modified concrete in fresh and hardened state. In Advanced Materials Research (Vol. 687, pp. 204-212). Trans Tech Publications.

[4] Bedi, R., Chandra, R., & Singh, S. P. (2013). Mechanical properties of polymer concrete. Journal of Composites, 2013.

[5] Abo-Dief, H. M., Ebrahim, F. F., Altalhi, A. A., & Mohamed, A. T. (2015). Development of Polymer Usage in the Concrete Composites for Buildings and Repairing Concrete Structures in KSA. International Journal of Advanced Scientific and Technical Research, 2(5).

[6] Arooj, M. F., Haydar, S., & Ahmad, K. (2016). Development of Economical Polymer-modified Concrete for Repair of Concrete Structures in Pakistan. Pakistan Journal of Engineering and Applied Sciences.

[7] Gupta, S. K., & Kumar, M. USE OF POLYMER CONCRETE IN CONSTRUCTION.

[8] S. K. Hirde, Omprakash S. Dudhal. (2016) Review on Polymer Modified Concrete And Its Application To Concrete Structures. international Journal of Engineering Research Volume No.5 Issue: Special 3, pp: 766-769

[9] Gorninski, J. P., Dal Molin, D. C., & Kazmierczak, C. S. (2007). Strength degradation of polymer concrete in acidic environments. Cement and Concrete Composites, 29(8), 637-645.

[10] Ohama, Y. (1997). Recent progress in concrete-polymer composites. Advanced Cement Based Materials, 5(2), 31-40.

[11] Mani, P., Gupta, A. K., & Krishnamoorthy, S. (1987). Comparative study of epoxy and polyester resin-based polymer concretes. International journal of adhesion and adhesives, 7(3), 157-163.

[12] Vipulanandan, C., & Dharmarajan, N. (1987). Flexural behavior of polyester polymer concrete. Cement and Concrete Research, 17(2), 219-230.

[13] Abdel-Fattah, H., & El-Hawary, M. M. (1999). Flexural behavior of polymer concrete. Construction and Building Materials, 13(5), 253-262.

[14] to [25] cited in [4].

[26] Zia, J., & Paul, S. Study on Effect of Polymer on Fiber Reinforced Repair Concrete.

[27] to [45] cited in [4]