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FABRICATION OF POLYMER CONCRETE OF LIGHT WEIGHT AND HIGH PERFORMANCE

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ABSTRACT: Concrete demonstrating high durability, lightweight, and high strength is demanded by a growing number of building projects. Concrete with these properties was achieved in Jordan by employing widespread local raw materials to make Lightweight High-Performance Polymer Concrete (LHPPC). The present study sought to assess the impact of new concrete mixture weight enhanced with polymers in various concentrations on the compressive and tensile strengths alterations as well as to promote the adoption of LHPPC technology in the construction industry. To that end, preparation of 300 concrete test samples was undertaken to enable measurement of compressive and tensile strength after curing intervals of 3 to 28 days. The samples consisted of two categories sub-classified C-20 and C-40 composition designs of aggregate to standard, with addition of polymers in different concentrations (2.5%, 5%, 7.5%, 10%, and 15%) according to the plain concrete weight. The findings revealed that the addition of polymers caused a strength reduction by 40% and 30% for C-20 and C-40, respectively, but the concrete mixtures were still suitable for use in construction. When polymers were added in a proportion of 15%, plain concrete displayed a weight reduction of up to 10%. Tensile strength diminished by just 15% compared to standard concrete when polymers were added in a proportion of 10%. Based on such findings, LHPPC should be produced in line with the specifications of each construction project, particularly in cases of cost increase exceeding 200%.

Keywords: Polymer, Performance, Strengths, Lightweight, Construction

1. INTRODUCTION

A blend with a cement content exceeding 400 kg/m^3 and compressive strength at 28 days exceeding 50 MPa is known as High-Performance Concrete (HPC) [1]. Meanwhile, ecological concrete that makes best use of raw materials, demonstrates high compressive strength, as well as being workable and durable, is known as High-Strength High-Performance Concrete (HSHPC) [2]. To enhance standard concrete microstructure, this type of concrete requires supplementary material. There is evidence that the properties of concrete can be successfully enhanced with mineral additives such as fly ash [3] and silica fume [4]). This is important particularly given the current growing concerns about the environment [3,4].

The effect of two types of polymer fibres, namely, polyvinyl alcohol and polyvinyl acetate, on concrete strength was examined, revealing that maximum compressive strength was achieved with modified-polymer concrete of 2% polymer/cement, while the strength of 6% polymer/cement did not differ much from standard concrete [5].

Stemming from the polymerisation of a mixture of monomer and aggregate, polymer concrete represents a composite material. The polymerised monomer serves as aggregate binder and the generated composite is known as “concrete”. Building cladding was among the first uses of polymer concrete. Subsequently, it started being employed as repair material due to properties such as fast curing, exceptional adhesion to cement concrete and steel reinforcement, durability, and high strength [6].

The preparation conditions dictate the properties that polymer concrete displays. Mixture content, aggregate size distribution, microfiller type, and curing conditions all influence the properties of a specific kind of polymer concrete [7,8]. Apart from their initially intended uses, polymer concrete materials have come to have other common uses as well. This is because of the ideal properties they display, including rapid curing, high compressive strength, high specific stiffness, non-susceptibility to chemical agents and corrosion, formation of shapes of high complexity, and exceptional vibration damping properties.

The generally indicated concentration of resin is up to 20% by weight of polymer concrete. The resin concentration determines the compressive strength of polymer concrete, according to previous research on polyester resin concrete with fluctuating concentration of resin [9,10]. The rise in polymer content stimulates a proportional rise in compressive and flexural strengths, which, upon peaking, decline or stay the same as the resin content is increased even more. In the current case, the ideal resin concentration will be the minimal polymer content associated with maximal properties. A resin content of 14-16% by weight has been found by a number of studies to be correlated with the highest flexural strength and compressive strength. Furthermore, one study has indicated that the polymer concrete compressive strength varied according to resin type and concentration [11]. A 12% resin concentration has been identified as yielding the maximum strength, regardless of resin type. Meanwhile, a resin concentration of 15% led to a reduction in strength in the case of two types of epoxy resins, but such an increase had no significant impact on strength in the case of polyester resin. In addition, the employed aggregate type influences the ideal resin concentration for a given polymer concrete system. For instance, fine aggregates have an extensive surface area, so an elevated concentration of resin is advised [12-14].

Ample research has been conducted on the use of unlike in nature, form, or quality types of fibres to reinforce polymer concrete. Thus, efforts have been made to enhance the properties of polymer concrete through the addition of stell, glass, carbon, and polyester fibres. In the majority of cases, the used content of glass fibres was 0-6% by weight of polymer concrete. There is evidence that the post-peak conduct of polymer concrete is enhanced when glass fibres are added. Furthermore, polymer concrete becomes stronger and tougher when fibres are added. A number of studies revealed that the mechanical properties of polymer concrete were increased by nearly a quarter when glass fibres were treated with silane prior to their incorporation in polymer concrete [16, 4].

There is widespread agreement among researchers that aggregates should be subjected to heat-assisted drying prior to being mixed with resin. Furthermore, the water content of the aggregates should not exceed 0.1% because it displays a significant effect on polymer concrete strength [17]. However, subsequent studies suggested that the water content can be up to 0.5% and still achieve improved mechanical properties [18-21].

A range of curing regimes have been proposed, including room temperature curing, high temperature curing, and water curing. Studies have reported that room temperature curing enabled polymer concrete to attain 70-75% of its strength after a single day [21,22]. By contrast, only around 20% of the strength at 28 days is attained by standard Portland cement within a single day. Precast applications stand to benefit from such early achievement of strength, as it improves resistance to higher stresses caused by various factors from an early stage. In addition, seven-day dry curing has been indicated to minimise variation in the compressive strength of polymer concrete [23].

The polymer in concrete either could be perform the function as binder with or without cement in form of polymer modified concrete, polymer concrete or polymer reinforcement concrete, or filler. Polymer as binder would enhance the interfacial framework, and polymer as filler would fill the void. Therefore, it would result minimal porosity concrete [24].

Through the investigation of different sizes of aggregates and different additions of polymer, the present work seeks to establish the ideal lightweight and High-Performance Concrete. Since the properties of treated aggregates have not been studied so far, this work addresses this gap in knowledge by analysing how effective treated or recycled polymer are as a substitute for common concrete production.

Due to cost issues, polymer concrete typically contains low binder, so aggregate binding is achieved via fine resin layer surround the aggregates. Hence, it is necessary to expand the contact area, which can be made possible by using smaller aggregates or microfiller particles to fill the existing voids. [25,26]. In the case of the integral blend technique, studies have found that the best results are obtained with a silane content of 1% by resin weight [27,28].

2. EXPERIMENTS

The objective of the present study was to govern how the mechanical properties and weight of concrete responded to polymer addition. To that end, Portland cement, sand, and limestone gravels were mixed to produce a control sample, followed by the production of C-20 and C-40 composition design mixture modified concrete samples through addition of polymers in different concentrations and use of different ratios of water to cement. The compressive strength, splitting tensile, durability, water absorption were assessed by subjecting the concrete mixtures with varying setting time to experimental tests. As mentioned by [7,8] the preparation conditions dictate the properties that polymer concrete displays. Mixture content, aggregate size distribution, microfiller type, and curing conditions all influence the properties of a specific kind of polymer concrete. The recycled polymer crushed and sieved through 4.75 mm mesh and mechanically mixed with the chosen concrete composition C-20 and C-40, and then

Portland cement and water added according to these designs. The empirical work employed Ordinary Portland Cement (OPC) produced by a cement factory company in Jordan. Table 1 provides the chemical cement properties and fineness. Sand was the fine aggregate used, whilst limestone gravel with different grading was the chosen coarse and medium aggregate (Table 2).

Table 1. The chemical properties displayed by type-II pozzolanic Portland cement

Property	Result (%)	Limitations
Chloride (Cl^-)	0.033	≤ 0.10
Sulfate (SO_3)	3.18	≤ 3.5
Insoluble Residue	11.79	--
Cement Fineness		
Description	Weight (g)	
Sample weight	500	
Empty sieve weight	582	
Sieve + Retained weight	594.6	
Retained weight	12.6	
%Retained = (M1/W3)*100 = 2.5 %		

Table 2. Particle size analysis on used aggregate samples

	Coarse -Medium Aggregate				
Sieve size (mm)	19.00	9.53	4.75	2.36	1.18
Coarse	62	1	0.9	0.8	0.8
Medium	100	35	3.3	3	2.7
Sieve size (mm)	19	4.75	0.30	0.15	0.075
Fine	100	98.4	13.5	4.1	2.7

Aggregates and fillers typically account for over 75-80% of the volume in polymer concrete. Aggregates usually occur as inert materials scattered all through the polymer matrix. The addition of aggregates is generally done according to two classes of size, namely, coarse and fine aggregates. The former consist of material of over 5 mm in size, while the latter are smaller than 5 mm. So far, standardisation of aggregate grading for polymer concrete has not been introduced, so there is significant variation between systems in terms of grading.

Table 3 presents the specific gravity associated with the aggregates. The average impact value was 13.37%, while a percentage of abrasion of 25.3% was yielded by the Los Angeles test. Compliance with the ASTM standards was observed in every analysis procedure [29-36].

Table 3. The physical properties of aggregate

description	Coarse	Medium	Fine
Apparent specific gravity	2.78%	2.73%	2.48
Bulk specific gravity	2.65%	2.64%	2.38
Water absorption Abs	1.81%	1.24%	1.65%

Table 4 provides details about the polyethylene polymer employed and related properties, while Table 5 presents the composition and weight for 1 m^3 for C-20 and C-40 of the control concrete compositions mixtures. Table 6 indicates the modified mixtures produced on the basis of the control mixture with the fine aggregate substituted with a polymer added by different weight for C-20 and C-40. Moreover, the control mixture permitted analysis of the impact of the ratio of water to cement, which was 0.77 for C-20 and 0.57 for C-40.

Table 4. Polyethylene polymer properties

Physical Properties	Unit / Metric
Density	0.924 - 0.995 g/cm^3
Particle Size	5.00 - 1200 µm
Tensile Strength	7.60 - 43.0 MPa
Flexural Yield Strength	13.8 - 75.8 MPa
Compressive Strength	4.00 - 23.0 MPa

Table 5. Standard concrete composition weight

Type of material	Weight (kg/m^3) C-20	Weight (kg/m^3) C-40
Cement	260	380
Coarse aggregate	415	370
Medium aggregate	450	420
Fine aggregate	230	215
Sand	715	630
Water	200	215
W/C ratio	0.77	0.57

Cubic samples of identical size to the samples employed in the compressive test were used to perform the water adsorption test, namely, 150 mm × 150 mm ×150 mm. Meanwhile, 150 mm x 300 mm cylindrical samples were used for the splitting tensile test. All samples was preparing at room temperature of 25º C and then placed in water path of constant 90º C to the end of experiments. As reported by studies have that room temperature curing enabled polymer concrete to attain 70-75% of its strength after a single day [21,22].

Table 6. Polymer addition weight

Polymer	Weight (kg/m^3) C-20	Weight (kg/m^3) C-40
2.5%	18	16
5%	36	32
7.5%	54	47
10%	72	63
15%	107	95

3. RESULTS AND DISCUSSION

The impact of increasing polymer addition for C-20 and C-40 on compressive strength is detailed in Table 7 and Table 8. It can be observed that polymer addition had an unfavourable effect, with compressive strength declining as the polymer concentration was increased. The effect of polymer addition declined compressive strength from 34.6 MPa to 23.7 MPa and from 44.4 MPa to 31.3 MPa on C-20 and C-40 respectively after 28 days of curing ages.

Table 7. C-20 compressive strength (MPa)

Polymer additives	3 days	7 days	21 days	28 days
0%	21.7	26.8	32.4	34.6
2.5%	21.8	25.5	31.2	32.1
5%	17.4	22.9	28.9	29.9
7.5%	15.6	19.8	25.1	26.1
10%	15.4	18.2	23.0	23.7
15%	13.2	16.1	20.0	20.8

Table 8. C-40 compressive strength (MPa)

Polymer additives	3 days	7 days	21 days	28 days
0%	25.9	32.8	38.5	44.4
2.5%	25.2	31.5	36.6	43.0
5%	24.6	31.7	36.8	42.8
7.5%	24.0	28.9	36.0	38.4
10%	22.5	28.3	32.8	33.9
15%	21.2	26.3	31.1	31.3

The lowest compressive strength was associated with polymer content of 0-15%, as can be seen in Fig. 1 and Fig. 2. Compared with the standard concrete, the maximum compressive strength was achieved at 2.5% polymer addition, reaching 32.1 MPa at 28 days. However, at polymer addition of more than 5%, 7.5%, 10%, and 15%, the compressive strength declined after 28 curing days. The aggregate composition may be varied to obtain different mechanical properties, as can the amount of polymer. Increasing polymer content caused decrease in compressive strength due to lubricant effect of the polymer particles in the cement matrix. The results mentioned in table 7 and table 8 shown that the polymer additive does not help in improve the compressive strength of the concrete. In spite of the fact that the polymer particles have filled up the void space in the concrete, they are not wholly incorporated into the concrete mix. This lead to the bonding between the concrete particles become weak.

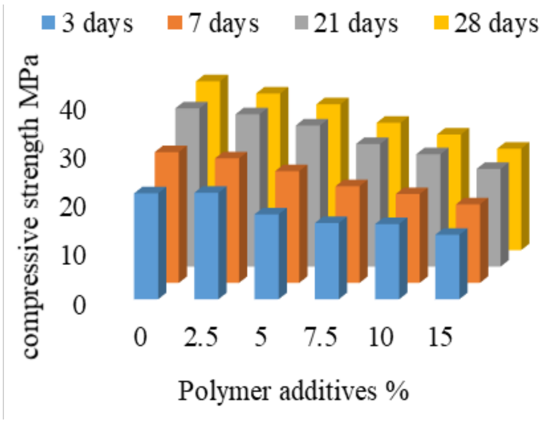

Fig. 1 C-20 compressive strength (MPa)

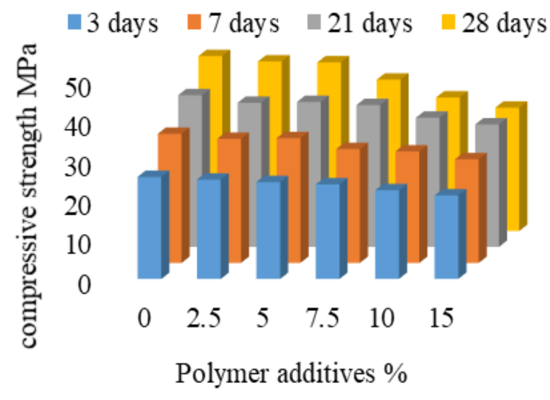

Fig. 2 C-40 compressive strength (MPa)

Nevertheless, the rise in polymer concentration determined an increase in compressive strength at both 3 and 28 days of curing for the same designs. Of particular significance was the effect of aggregate grading on polymer concrete properties. In the case of modified mixtures produced on the basis of the control mixture with sand substituted for polymer, compressive strength declined as polymer addition was increased, reaching 20.8 MPa and 31.3% MPa for C-20 and C-40, respectively, at 15% polymer content. By comparison, the standard mixture had a compressive strength of 34.6-44.4 MPa as shown in Table 9 and Fig. 3. The proportions of coarse and fine aggregates should be chosen in a manner that minimises voids and maximises bulk density in the aggregate mixture.

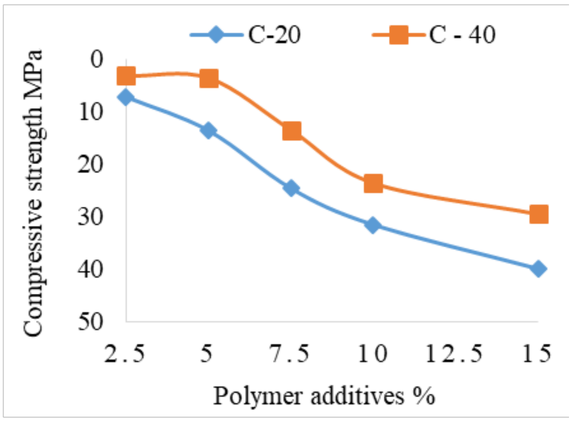

Figure 3. Compressive strength decline

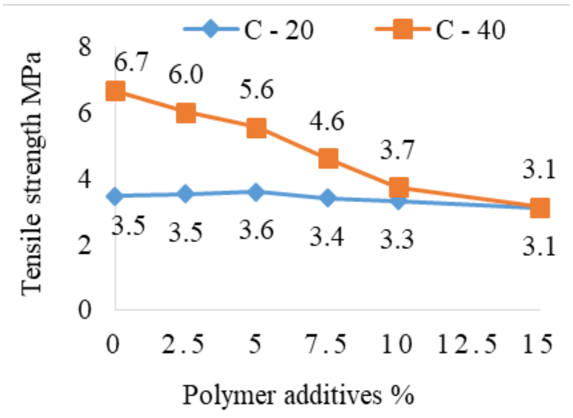

Fig. 4 Tensile strength

The response of the C-20 and C-40 splitting tensile strength to polymer addition is illustrated in Fig. 4. The maximum polymer concentration of 15% was associated with the lowest splitting strength. The interactivity between blended cement and higher polymer additions will get unfavourable result due to resulting void while setting and in curing process, and this will lead to decreasing of concrete strength. Optimal splitting strength can be achieved with polymer use, but tensile strength was reduced by polymer addition. It is especially notable that increased polymer concentration resulted in a tensile strength of 3.1 MPa for both C-20 and C-40.

Similar results was obtained by researchers that concluded a decreased in both compressive and splitting tensile strength as a polymers increase. For overall, the tensile splitting strength of the concrete seems does not have enhancement after blending with the polymer additive. The concentration of polymer higher than 1% resulting negative effect to static and dynamic characteristic, except modulus of elasticity [37,38].

There was a considerable decrease in weight as the polymer concentration was increased. The reason for this was that the addition of polymer latex reduced the proportion of fine aggregates. Tables 9 and 10 and Figure 5 provide more details on the results related to weight and strength.

Table 9. The degree of compressive strength decline after 28 days of curing

polymer	C-20	C - 40
2.5 %	7.2	3.2
5 %	13.6	3.6
7.5 %	24.6	13.5
10 %	31.5	23.6
15 %	39.9	29.5

Table 10. The degree of weight reduction of 1 m^3

% polymer	Weight of concrete Kg /m^3		% of decrease in weight	
	C-20)	C-40	C - 20	C - 40
2.5 %	2245	2210	1.4	1.3
5 %	2213	2181	2.8	2.6
7.5 %	2186	2152	4.0	3.9
10 %	2154	2123	5.4	5.2
15 %	2089	2064	8.3	7.9

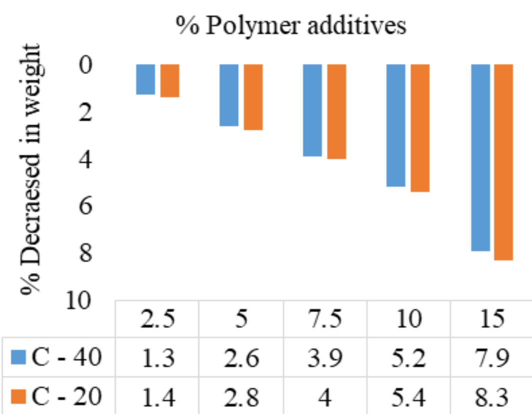

Fig. 5 The degree of weight reduction of 1 m^3

The cost of polymer concrete is a significant aspect in favour of the use of such mixtures in construction projects where weight reduction is necessary. Fig. 6 show cost changes in relation to polymer addition.

Concrete made from conventional lime-containing cement unfortunately is not well suited for use in structures that are exposed to high acidity, chemical leaching attack, or other harsh conditions. Addition of polymer into concrete admixture could be used for eliminating concrete limitation. Acid tanks, manholes, drains, and highway median barriers are just some of the items that are fabricated with precast polymer concrete**.** For this reason, a higher price may be considered acceptable for such purposes**.**

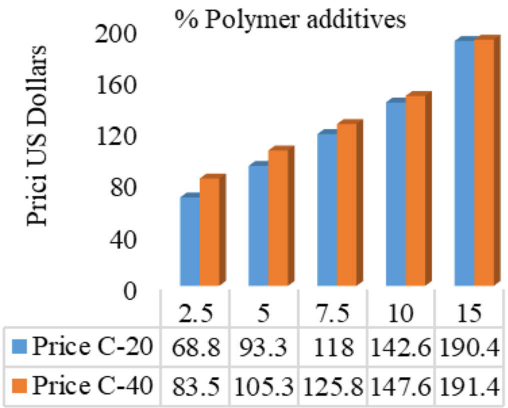

Fig. 6. Cost of modified polymer concrete per 1 m^3

4. CONCLUSIONS

The findings of the experiments undertaken in this study allow several conclusions to be formulated. First of all, ideal results for the selected mixture designs were achieved with polymer concentrations of 2.5% and 5%. Secondly, both C-20 and C-40 displayed compressive strength reduction when fine aggregates and sand were substituted with polymer in different concentrations. Thirdly, the aims of each construction project must be considered in determining the ideal polymer mixture regarding weight changes. Fourthly, tensile strength may be altered by adding polymer, but may remain unchanged after further addition. Finally yet importantly, polymer mixture is more expensive than standard mixture design.

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