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Materials and Methods

Metakaolin (SiO_2 = 52.64%, Al_2O_3 = 34.9% and Na_2O = 1.84%), obtained by calcining of kaolin clay at 750 °C for three hours using heating rate of 10 °C/min, was used as a source for alumino-silicates. The kaolin was supplied from the local market, the origin of this clay is "Dwaikhla" region in the west of Iraq. The alkaline activator is a solution of commercial sodium silicate (Na_2O = 13.1-13.7%, SiO_2 = 32-33 % and H_2O = 53.3-54.9%) from the UAE and sodium hydroxide from Caustic Soda Company. The coarse and fine aggregates were obtained from the western desert of Iraq. Crumb rubber is from Al-Diwaniyah company for tyres industry, Iraq. Maliec Anhydride and Benzoyl Peroxide for treatment of crumb rubber were from CDH company, India.

Experimental work

The alkali activator was prepared by dissolving the required amount of sodium silicate solution and sodium hydroxide in water. Firstly, sodium hydroxide was weighed and added to the required water. As the sodium hydroxide pellet dissolves in water, heat was generated, so the solution was cooled to room temperature before use. The sodium silicate solution was added to the solution. A desired amount of water was added to the solution to supply the geopolymer with the required amount of water. Then, the solution was subjected to heat treatment that involved heating the solution at 80 ± 5 °C for 25 min under stirring at 500 rpm, additional water was added to this batch to recompense the water lost due to evaporate. Then, the solution was kept for one day at ambient conditions before use.

The alkali solution subjected to the heat treatment was used to prepared geopolymer paste with different SiO_2/ Al_2O_3 ratio of 3.4, 3.6, 3.8 and 4 and different amount of water of 8, 9, and 10 ml in order to optimize the compressive strength as showed in Table 1. The geopolymer paste was prepared by adding the metakaolin powder to the activator solution under mechanical mixing at a speed of 3000 rpm for a total mixing time of 5 min. The geopolymer pastes were molded in plastic moulds with 2.1 cm of diameters and 4.2 cm of heights. The samples were kept at room temperature for one day before removing from mold. The samples were then cured at room temperature for 28 days before testing.

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Table 1. The Geopolymer Mixes with Heat Treatment of Alkali Activator

Sample	SiO_2 / Al_2O_3	H_2O (ml)
GP1	3.4	8
GP2	3.4	9
GP3	3.4	10
GP4	3.6	8
GP5	3.6	9
GP6	3.6	10
GP7	3.8	8
GP8	3.8	9
GP9	3.8	10
GP10	4	8
GP11	4	9
GP12	4	10

To increase the bond strength between the rubber and geopolymer paste, crumb rubber treated with Maleic Anhydride (MAn) were used. The treatment was attained in closed stainless steel mixer made by the researcher, where the temperature was set at 220 ^{0}C and the treatment continued for 80 min. Each 1 gm of powder or crumb rubber was well mixed with 0.1 gm of maleic anhydride (MAn) and 0.01 gm of the initiator benzoyl peroxide (BPO) as described by [12].

The mix of geopolymer paste that yields the highest compressive strength and the crumb rubber that treated with MAn and fine and coarse aggregate were used to prepared the lightweight geopolymer concrete, where the pre-treatment by MAn of crumb rubber and powder rubber were partially replaced in a ratio of (5, 10, 15%) by volume of the fine and coarse aggregate in the geopolymer concrete. The amount of materials including the metakaolin, Na_2SiO_3, NaOH, H_2O, fine aggregate, coarse aggregate, crumb rubber (CR) and powder rubber (PR) are given in Table 2. The mixes were casted in a steel mould (70 * 70 * 70 mm for compression test) and (70 * 70 * 280 mm for flexural test) and cured at ambient temperature. Demolding took 24 hr, and the concrete was kept at room temperature for 28 days before test.

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Table 2. Lightweight Geopolymer Concrete Mixes

Sample no.	MK (kg)	Na_2SiO_3 (kg)	NaOH (kg)	H_2O (ml)	Fine aggregate (kg)	Coarse aggregate (kg)	CR (kg)	PR (kg)
GPR0	286.3	288.8	21.4	40.1	554.4	1293.6	0	0
GPR5	286.3	288.8	21.4	40.1	526.6	1244.8	26.2	12.8
GPR10	286.3	288.8	21.4	40.1	498.9	1179.3	52.4	25.7
GPR15	286.3	288.8	21.4	40.1	471.2	1113.8	78.3	38.5

Characterization Techniques

The density, water absorption, and porosity of the prepared specimens were assessed using the Archimedes method. Compression test was accepted according to ASTM C109 [13], where compressive strength calculated from divided the load required to fracture of sample on the area of sample σ (MPa)= P(kN) /A(mm^2). At 28 days old, flexural test of geopolymer concrete underwent this test according to ASTM C78 [14], where Flexural Strength (N/mm^2) = [3PL /2 bd^2].

Results and Discussions

The results of density, water absorption and porosity of geopolymer paste after 28 days were shown in Table 3. It shows that the lower water absorption was 22.01% at 3.2 mole silica and 8 ml water, and the maximum porosity was 39.731% at 3.2 mole silica and 10 ml water, the lower bulk density was 1.318 gr/cm^3 at 3.2 mole silica and 10 ml water. For all mixes the increased water lead to increased porosity that lead to decreased density and increased water absorption of geopolymer paste.

The density of lightweight geopolymer concrete at 28 days is shown in Figure 1. The results clearly demonstrate that the density of the lightweight geopolymer concrete decreases with increasing crumb rubber percentage. Based on the results, the lightweight geopolymer concretes' unit weights varied from 2141 kg for reference mix concrete to 2043 kg for concrete have 15% replacement of crumb rubber, where the reduction percentage of weight is 4.57%. As crumb rubber loading increased, the lightweight geopolymer concrete's unit weight decreased, making the finished product lighter. The findings suggest that lightweight geopolymer concrete mixes had lower unit weight than ordinary concrete, which was caused by crumb rubber's low specific gravity.

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Table 3. Water Absorption, Porosity and Density of Geopolymer Paste

Batch Number	Water absorption%	Porosity %	Bulk density(gr/cm^3)
GP1	22.01	33.208	1.508
GP2	27.91	39.081	1.4
GP3	30.142	39.731	1.318
GP4	23.129	33.678	1.456
GP5	27.997	38.989	1.392
GP6	31.17	43.84	1.338
GP7	25.545	36.25	1.419
GP8	27.709	39.494	1.425
GP9	30.51	40.91	1.394
GP10	22.229	32.679	1.47
GP11	24.723	36.301	1.468
GP12	29.69	40.444	1.362

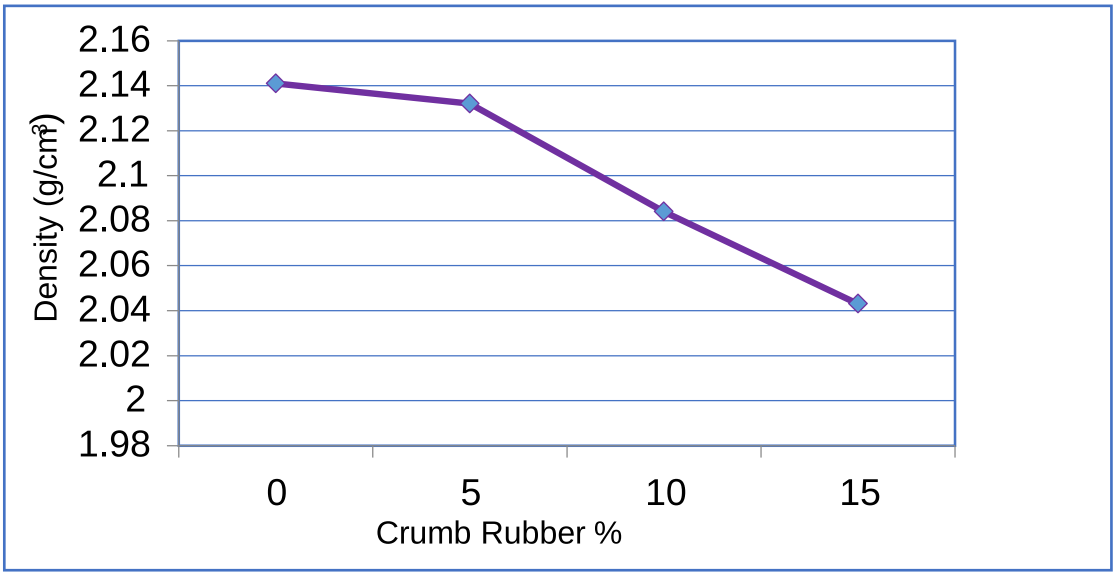

Figure 1. Density of Lightweight Geopolymer Concrete

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As shown in Figure 2, the porosity of lightweight geopolymer concrete was raised in all mixes for both fine and course aggregate, this is due to the trapped air in the crumb rubber causes pore forming inside the concrete, in addition to the density of rubber is lower than that density of fine and coarse aggregate.

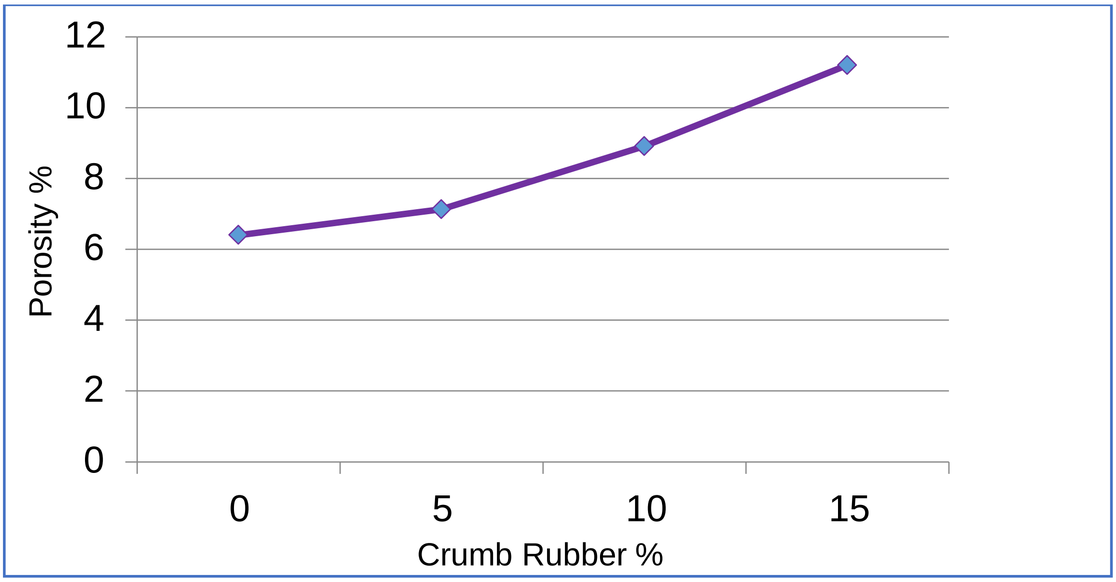

Figure 2. The Porosity of Lightweight Geopolymer Concrete

Table 4. shows the values of compressive strength of geopolymer paste samples prepared using alkali solution with heat treatment. It can be seen that the heat treatment for the alkali solution improves the compressive strength, this can be attributed to the breakdown of the sodium silicates chains, by the NaOH during the heat treatment, resulting in more number of oligomers that building of the 3D network of geopolymer.

It can be noted that the compressive strength increases for the mixes that have low water amount, as the increase of water leads to increase of porosity, as can be seen from Table 4. which decreases the compressive strength of geopolymer paste. Also, as the polymerization reaction is a condensation reaction, the presence of the access water enhances the breakdown reaction and, hence, decrease the strength.

The highest obtained compressive strength of geopolymer paste after 28 days is 117.1 MPa at the ratio of SiO_2/Al_2O_3 of 3.6 and 8 ml of water, this geopolymer was used as binder material to prepared the lightweight geopolymer concrete.

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Table 4. Compressive Strength Values of Geopolymer Paste after 28 days

Batch Number	Compressive strength (MPa)
GP1	95.8
GP2	90.6
GP3	90.7
GP4	117.1
GP5	89.15
GP6	56.7
GP7	97.3
GP8	77.88
GP9	75.34
GP10	99.58
GP11	62.4
GP12	48.6

This value of the compressive strength is too higher as compared with that only reported for geopolymer without any addition or reinforcement as shown in Table 5

Table 5. Comparison of Compressive Strength of Geopolymer Paste after 28 Days with other Researches

Compressive strength (MPa)	References
59.4	[15]
30	[16]
65.4	[17]
117.1	Current study

This result can be attributed to money reasons:
1- The effect of heat treatment of the alkali solution.
2- The use of low water contain.
3- Curing of low temperature that enhance the exothermic geopolymerization reaction.
4- The use of appropriate geopolymer formulate.
Table 6 shows the compressive strength values of lightweight geopolymer concrete after 28 days, where the compressive strength was reduced when the percentage substitution of crumb rubber raised from 0 to 15 % by volume of both coarse and fine aggregate. This is because

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the crumb rubber has lower strength than the aggregate and, may be, due to the trapped air that produce pores in the structure of the geopolymer that was negative impact on compressive strength

Table 6. Compressive Strength and Flexural Strength Values of Lightweight Geopolymer Concrete After 28 Days

Samples	Compressive strength (MPa)	Flexural strength (MPa)
GPR0	60.6	6.076
GPR5	41.12	5.195
GPR10	29	5.117
GPR15	25.1	3.698

Flexural strength of lightweight geopolymer concrete reduced at the proportion replacement of crumb rubber was increased for both fine and coarse aggregate as shown in Table 6

Conclusion

1- The heat treatment of alkali activator is important to increase the compressive strength of geopolymer paste for a value as high as 117.1 MPa.
2- The increased of SiO_2/Al_2O_3 ratio and amount of water in the geopolymer paste lead to decrease of the compressive strength and density because of the increase of porosity.
3- A geopolymer concrete with a high compressive strength of 60.6 MPa and low density, compared with the ordinary Portland cement concrete, can be prepared without any additives when the alkali solution is subjected to heat treatment.
4- Geopolymer concrete with a compressive strength of 60.6 MPa and flexural strength of 6.07 MPa can be obtained via slitting the proper value of the SiO_2/Al_2O_3 ratio, amount of water, and the fine and course aggregate.
5- Lightweight geopolymer concrete with adequate mechanical properties and cost can be produced using waste rubber materials with MSA surface treatment.

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تطوير الخرسانة الجيوبوليمرية خفيفة الوزن: دراسة المقاومة والكثافة

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الخلاصة

يتوقع ان يغير الجيوبوليمر مستقبل الاسمنت البورتلاندي. هدف هذه الدراسة هو تحضير خرسانة جيوبوليمرية خفيفة الوزن باستعمال مفروم المطاط كركام. محلول سليكات الصوديوم وهيدروكسيد الصوديوم استعملت لتحضير محلول التفعيل القلوي، الكاؤلين استعمل كمصدر للجزء الصلب للجيوبوليمر. مفروم المطاط استعمل كاستبدال جزئي بنسبة حجم (5، 10، 15%) من حجم الركام لإنتاج خرسانة جيوبوليمرية خفيفة الوزن. لتحسين قوة الترابط بين حبيبات المطاط والجيوبوليمر، تمت معاملة حبيبات المطاط بمادة مليك انهايدرايد (MAn).

عرض المحلول القلوي للمعاملة الحرارية، وتمت دراسة تأثير نسبة السليكا الى الالومينا وكمية الماء المستخدم، وكذلك تأثير مفروم المطاط على الخواص الميكانيكية (مقاومة الانضغاط ومقاومة الانحناء) والخواص الفيزيائية (المسامية ونسبة امتصاص الماء والكثافة) للخرسانة الجيوبوليمرية الخفيفة الوزن.

بينت هذه الدراسة ان المعاملة الحرارية للمحلول مهمة للحصول على مقاومة عالية، مقاومة تساوي 117 ميكا باسكال تم الحصول عليها عند نسبة سليكا الى الومينا تساوي 3.6 وكمية ماء 8 مل لعجينة الجيوبوليمر. مقاومة انضغاط 60.6 ميكا باسكال ومقامة انحناء 6.076 ميكا باسكال تم الحصول عليها لخرسانة الجيوبوليمر عند 554.5 كغم و1293.6 كغم للركام الناعم والخشن على التوالي. كذلك التجربة بينت بان المقاومة والكثافة للخرسانة الجيوبوليمرية خفيفة الوزن تقل مع زيادة نسبة الاضافة من ركام المطاط. كان النقصان بالوزن للخرسانة الجيوبوليمرية خفيفة الوزن حوالي 100 كغم للمتر المكعب الواحد عن خرسانة الجيوبوليمر العادي، وحوالي 300 كغم عند المقارنة مع خرسانة السمنت البورتلاندي.

الكلمات الدالة: ميتاكاؤلين، محلول تفعيل قلوي، جيوبوليمر , خرسانة خفيفة الوزن.