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Assessment of Porous Concrete Properties as a Function of Mix Proportions

Enas A. Khattab, Hanan A. El Nouhy and Ghada D. Abdel-Hameed

Building Materials and Quality Control Institute, Housing and Building National Research Center, Dokki, Giza, Egypt

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Abstract: The aim of this study is to investigate the properties of porous concrete as a function of its mix proportions. Mixtures were designed based on desired cement paste/total aggregate ratio to determine fresh concrete and hardened concrete properties. Twelve mixes were cast and tested. The 12 mixes were divided into 6 groups: Each group comprised two mixes. Concerning, group 1(mixes 1 and 2), the former contained 10 mm aggregate, while the latter included 5mm aggregate. Both mixes had cement paste/aggregate ratio of 0.2 and were sand free. The same is applied for group 2 (mixes 3 and 4) and group 3(mixes 5 and 6). However, groups 2 and 3 had cement paste/aggregate ratios of 0.3 and 0.4 respectively. Group 4 (mixes 7 and 8), group 5 (mixes 9 and 10) and group 6 (mixes 11 and 12) were similar to those of groups 1, 2 and 3, respectively, except that the used coarse aggregates was partially replaced with 10% sand. Tests carried out on fresh concrete were slump, density and compaction index. Tests conducted on hardened concrete were compressive strength, splitting tensile strength, flexure strength, permeability, as well as flow rate. Results have shown that it is possible to produce porous concrete with acceptable porosity and compressive concrete strength.

Key words: Compaction factor · Compressive strength · Flow rate · Porosity · Slump

INTRODUCTION

Porous concrete was developed as an environmentally friendly material in Japan in the 1980's as it has multiple environmental benefits: restoring groundwater supplies, reducing water and soil pollution [1]. Porous or pervious concrete is concrete with continuous voids which are intentionally incorporated into concrete. It is a special type of concrete and consequently its physical characteristics differ greatly from those of conventional concrete. Porous concrete can be utilized in various applications such as permeable concrete for pavement, base course, noise absorbing concrete, thermal insulated concrete and other civil engineering and architectural applications [2]. Also a special type of porous concrete was designed to be used in protective structures such as safety walls or storages for explosives [3]. It may also allow credits to be obtained in green rating scales for sustainable construction as porous concrete is regarded an innovative approach to sustainable road pavement design and construction. However, from the construction management point of view, disadvantages include the need to closely apply quality management to pavement, mix design and concrete placement. Also, another potential disadvantage with permeable concrete pavements is the ability to manage clogging issues like muddy water [4]. Porosity typically ranges from 15% to 30% and the characteristic pore sizes range from 2 mm to 8 mm depending on the type of the used aggregates and the method of compaction [5]. The strength of porous concrete is significantly affected by the porosity of its internal structure. The establishment of a quantitative relationship between porosity and concrete compressive strength was investigated. A model, derived from Griffith's theory demonstrated that prediction of porous concrete compressive strength based on its material porosity [6]. A previous study was conducted in which mixtures of different pore structure features were proportioned and subjected to static compression tests. Larger aggregate sizes and incease in paste volume fractions resulted in increased concrete compressive strength. In addition, the compressive

Corresponding Author: Hanan A. El Nouhy, Building Materials and Quality Control Institute, Housing and Building National Research Center, Dokki, Giza, Egypt.

response was found to be influenced by the pore sizes, their distributions and spacing [7]. The strength, fracture toughness and fatigue life of two types of pervious concrete, supplementary cementitious material modified pervious concrete (SPC) and polymer- modified pervious concrete (PPC) were investigated. Results show that PPC demonstrated much higher fracture toughness and far longer fatigue life than SPC at any stress level [8].

Also, a study was performed to evaluate the physical, mechanical and sound absorption characteristics of porous concrete. Design was based on the Target Void Ratio (TVR) and the content of the recycled aggregates. The objectives were to reduce noise generated in roads as well as utilize recycled waste concrete aggregates. Test results demonstrated that the optimum void ratio is 25% and the recycled aggregates content is 50% regarding compressive strength and Noise Reduction Coefficient (NRC) [9]. The influence of cement flow and aggregate type on the mechanical and acoustic characteristics was also studied. Based on the findings, a sound absorbing concrete with a maximum absorption coefficient of approximately 1.00 was developed [10]. The development of porous concrete with acceptable permeability and strength using recycled aggregate was also investigated. The obtained results showed that it is feasible to use recycled aggregate with optimum content of polymer to produce acceptable porous concrete with both enough drainage and strength properties [11]. Another research was conducted in which the performance of laboratory and field produced pervious concrete mixtures as well as field cores were evaluated and compared through laboratory performance tests, including air voids, permeability, compressive and split-tensile strengths, as well as, freeze-thaw durability tests. The comparison between laboratory and field mixtures showed that a properly designed and laboratory verified pervious concrete mixtures could meet the requirements of permeability, strength and durability [12]. Also, the properties of porous concrete were investigated with regard to cement paste characteristics [13]. Another study was performed to evaluate pervious concrete test specimen preparation techniques in an effort to produce specimens having properties similar to in-place pervious concrete pavement. Cylinders and slabs were cast using different procedures. The comparisons of cast specimens to pavement cores were based on infiltration rate, density and porosity. Regarding cylinder consolidation procedures tested, the standard proctor hammer provided the least variability of results and yielded properties similar to the in-place pavement. However, the 600mm square slabs were even more consistent with the in-place pavement density and porosity [14]. Tittarelli *et al.* [15] conducted a study in which the CO_2 was induced to study corrosion behavior of no-fines concrete manufactured with three different strength classes and reinforcements. Among the reinforcements considered (black steel, galvanized steel and steel covered with cement grout), galvanized steel showed the best corrosion behavior. Sumanasooriya *et al.* [16] analyzed the pore structure features of concrete designed for similar porosities using two different proportioning methods-one with higher paste contents and lower compactive efforts and the another with low paste contents and higher compactive efforts. Test results demonstrated that the mixtures of low paste content had a higher specific surface area of pores.

MATERIALS AND METHODS

Materials and Mix Proportions: Ordinary Portland cement CEM I 42,5N and two different sizes of dolomite were used as coarse aggregates. They were: 10 mm (passing 14mm sieve, retained on 10mm sieve, single sized) and 5mm (passing 14mm sieve, retained on 5mm sieve, graded). Siliceous sand was used as fine aggregate and was in the medium grading zone according to Egyptian Code of Practice issued 2007. The specific gravity and volumetric weight of the used sand were 2.6 and 1.5 tons/m^3, respectively. The water/cement ratio was 0.27 for the 12 mixes. Superplasticizer admixture which complies with ASTM C494 Types G and F (0.5% by weight of cement) and tap water were used in all mixes. The 12 mixes were divided into 6 groups: Each group comprised two mixes. Concerning, group 1(mixes 1 and 2), the former contained 10 mm aggregate, while the latter included the 5mm aggregate. Both mixes had cement paste/aggregate ratio of 0.2 and were sand free. The same apply for group 2 (mixes 3 and 4) and group 3(mixes 5 and 6). However, groups 2 and 3 had cement paste/aggregate ratios of 0.3 and 0.4 respectively. Group 4 (mixes 7 and 8), group 5 (mixes 9 and 10) and group 6 (mixes 11 and 12) were similar to those of groups 1, 2 and 3 respectively, except that the used coarse aggregates was partially replaced with 10% sand. The properties of aggregates and mix proportions are presented in Tables 1 and 2, respectively.

Tests: The tests which were carried out on concrete in its fresh state were slump according to ASTM C143 [18], density and compacting factor test. Density was conducted using three methods: the standard one, simulated and loose. Cylinders of 300 mm height and

Table 1: Properties of used coarse aggregate.

Property	Crushed stone (1)	Crushed stone (2)	Acceptance limits*
Specific gravity	2.65	2.65	--
Volumetric weight (tons/m^3)	1.54	1.56	--
Absorption Percentage	1.46%	1.63%	Not more than 2.5%
Clay and other fine materials (%)	0.266%	0.533%	Not more than 3% by weight
Abrasion value (loss angeles) (%)	31.03%	26.5%	Not more than 30%
Crushing value (%)	18.93%	--	Not more than 45%
Impact value (%)	--	10.4%	Not more than 45%
Flakiness Index (%)	31.33%	31.2%	Not more than 25%
Elongation Index (%)	4.33%	3.87%	Not more than 25%

*According to the Egyptian Code of Practice issued 2007 [17]

Table 2: Mix proportions

Mix	Cement Content Kg/m^3	Water content kg/m^3	Coarse aggregate kg/m^3	Fine aggregate kg/m^3	Superplasticizer lt/m^3
G1	335	90.5	2128.0	0	1.68
G2	335	90.5	2128.0	0	1.68
G3	456	123.3	1934.0	0	2.30
G4	456	123.3	1934.0	0	2.30
G5	558	150.8	1774.0	0	2.80
G6	558	150.8	1774.0	0	2.80
G7	335	90.5	1908.0	212.0	1.68
G8	335	90.5	1908.0	212.0	1.68
G9	456	123.3	1737.4	193.0	2.30
G10	456	123.3	1737.4	193.0	2.30
G11	558	150.8	1593.6	177.1	2.80
G12	558	150.8	1593.6	177.1	2.80

150mm diameter were used in the three methods. The standard method was in accordance to ASTM C138 [19]. The simulated method, in which the concrete was poured in the cylinder without any compaction (one lift casting) and the top surface of the concrete was struck off by means of a screeding and rolling motion of the standard 16 mm tamping rod to simulate road paving. The loose method is exactly the same as the simulated one, with the exception that there was no rolling motion on the top surface. The compacting factor test was conducted according to ACI Standard 211.3 [20]. The tests which were conducted on hardened concrete were: compressive, splitting tensile and flexural strengths. Compressive, splitting tensile and flexural tests were determined in accordance with ASTM C39 [21], ASTM C 496 [22] and ASTM C 78 [23], respectively. The mixes were placed in moulds in one lift. One lift casting was used as it simulates actual placing condition in pavements. The specimens were demoulded after 1 day of casting and kept in water until testing age. Also, permeability (rate of flow) was measured. A mould of 30x30x10 cm was used and the sides were insulated. The upper surface was exposed to water. Water was poured on the top surface and collected from the lower surface after 30 seconds. The rate of flow was calculated as the quantity of water collected in 30 seconds divided by the area exposed to water. The effective porosity was determined by testing the volume of water displaced by samples. The sample was firstly oven dried at 110°C and then immersed in water for up to 24 hours. By measuring the difference in the water level before and after immersing the sample, the volume of water repelled by the sample (V_d) can be readily determined. Subtracting V_d from the sample bulk volume (V_b) yields the volume of open pores. This volume was then expressed as an effective porosity percentage:

$p_e = (V_b - V_d)/ V_b \times 100\%$ [6].

RESULTS AND DISCUSSION

Fresh and hardened concrete were tested to determine the effects of cement paste/aggregate ratios, grading of coarse aggregates, as well as, the partial replacement of coarse aggregates with 10% sand on the tested properties.

Fresh Concrete

Slump Test: The results of fresh concrete properties are presented in Table 3 and Photo 1. The results of groups 1, 2 and 3 demonstrate that the slump value was similar in the three groups irrespective of the cement paste/ aggregate ratios, dolomite grading and size. These results

Table 3: Fresh properties

Mix	Slump (cm)	Density (g/cm^3)	Loose density (g/cm^3)	Simulated density (g/cm^3)	Compaction factor (%)
G1	19.5	1.95	1.65	1.68	84.6
G2	21.3	1.90	1.58	1.61	83.2
G3	20.5	2.03	1.65	1.68	81.3
G4	23.0	1.98	1.61	1.76	81.3
G5	25.5	2.17	1.74	1.91	80.2
G6	20.0	1.96	1.73	1.81	88.3
G7	16.5	2.00	1.72	1.77	86.0
G8	19.0	1.95	1.66	1.69	85.1
G9	15.0	1.98	1.50	1.73	75.8
G10	18.0	2.09	1.68	1.87	80.4
G11	12.0	2.23	1.74	1.91	78.0
G12	19.0	2.30	1.81	1.88	78.7

Photo 1: Concrete slump

are in agreement with the findings of Bhutta *et al.* [1]. On the other hand, the inclusion of 10% sand in groups 4, 5 and 6 had major effects on slump values. When comparing mixes of groups 1, 2 and 3 with the corresponding mixes of groups 4, 5 and 6, it was noticed that slump values were decreased in the latter groups due to the inclusion of sand. The slump was lower in mix 9 with single sized aggregates when compared with mix 10 with graded aggregates. The same trend was noticed concerning mixes 11 and 12 respectively. The results of mixes 9 and 11 (same aggregate size and grading, but different cement paste/aggregate ratios), as well as mixes 10 and 12 show that the cement paste/aggregate ratios had minor effect on slump values.

Compaction Factor: All mixes yielded compaction factors that were in the range of 75.8% to 88.3%. This indicates that the mixes exhibited acceptable workability and cohesiveness. This could possibly be attributed to the use of appropriate quantity of superplasticizer to produce porous concrete to fill the spaces of almost any size and shape without segregation or bleeding. These results are in agreement with those reported by Bhutta *et al.* [1].

Density (Standard, Simulated and Loose Compactions): The standard compaction gave the highest density, while the loose compaction provided the least density concerning the tested specimens. At constant cement paste/aggregate ratio and assuming that the paste is relatively incompressible, the aggregate volume per unit total volume become higher in standard compaction because of the compactive effort. This explains why all the mixes provided higher density regarding full compaction. The densities' results of both the simulated and loose compaction were close. The increase in cement paste/aggregate ratio enhanced both the simulated and loose densities.

Hardened Concrete

Compressive, Flexural and Splitting Tensile Strengths: The compressive and flexural strengths were tested at ages 7 and 28 days respectively. The splitting tensile was tested at age 28 days. As expected, the 28 days compressive and flexural strengths were higher than those of 7 days. The use of graded coarse aggregates, the increase of cement paste volume, as well as the inclusion of sand attributed positively to the above-mentioned strengths. In fact, the most pronounced increase in the tested strengths was observed in mix 12 which included all the previously mentioned variables. The reduction in aggregate size, as is the case in the inclusion of sand, possibly attributed to better particle-to-particle packing and interlock, which in turn resulted in less voids, forming a continuous mass. The increase in cement paste provided more available coating to the aggregates, thus increased the contact area between neighboring aggregate particles. Consequently, strengths were improved. Pervious concrete mixtures can develop compressive strength in the range of 3.5 MPa to 28 MPa, which is suitable for a wide range of applications [24]. The 28-days compressive strength of the tested mixes was within the mentioned range. Flexural strength generally ranges between 1MPa and 3.8 MPa [25].

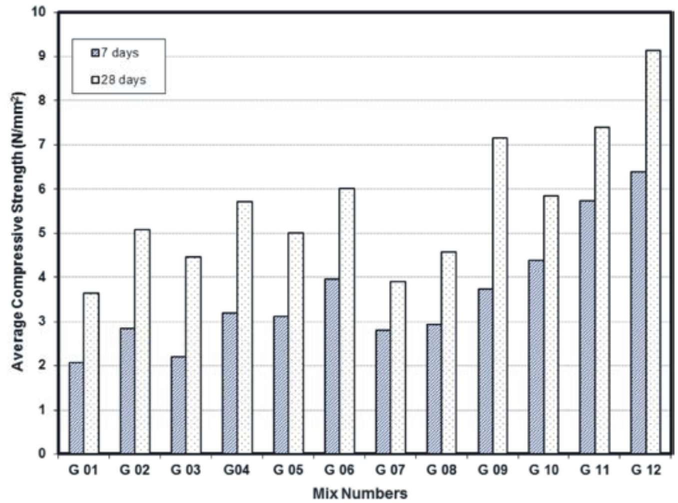

Fig. 1: Effect of mix proportions on average compressive strength

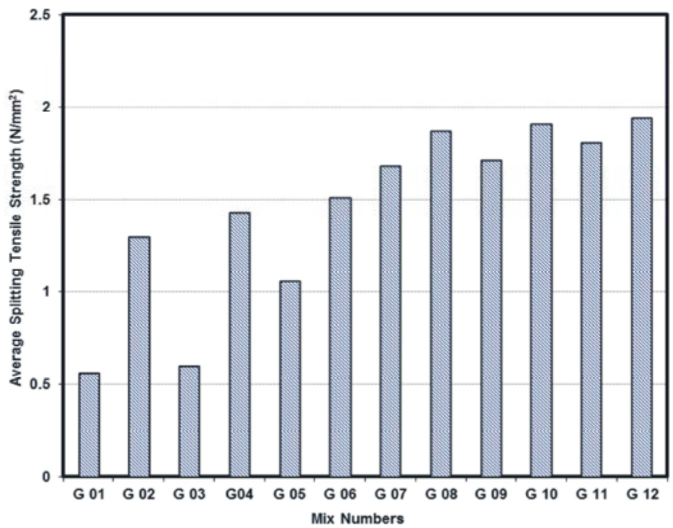

Fig. 2: Effect of mix proportions on average splitting tensile strength

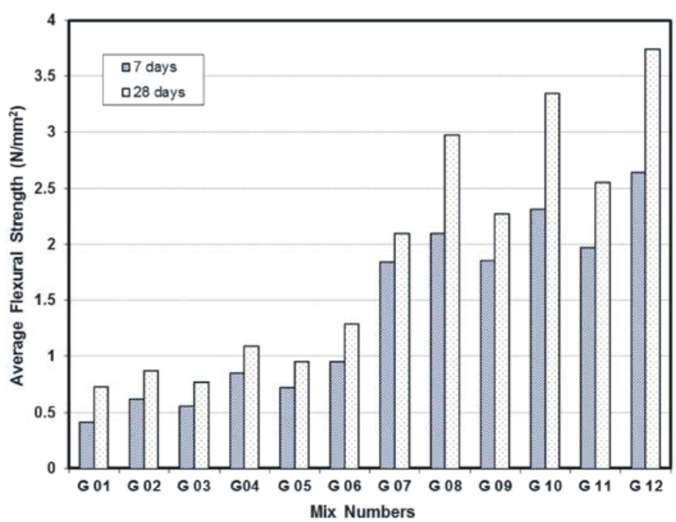

Fig. 3: Effect of mix proportions on average flexural strength

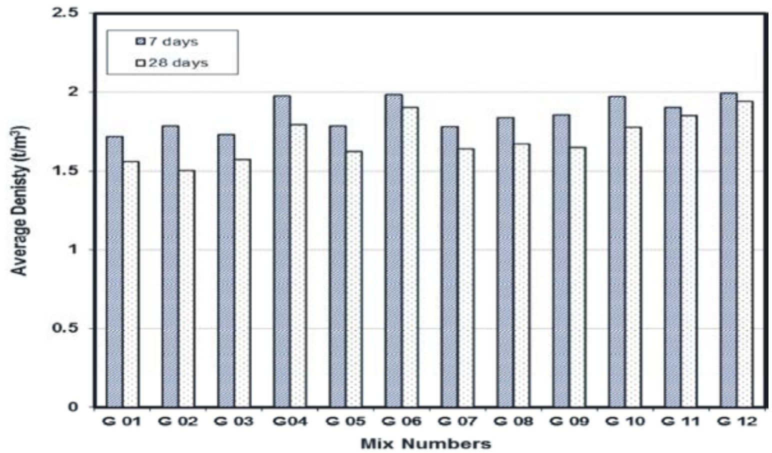

Fig. 4: Effect of mix proportions on average density

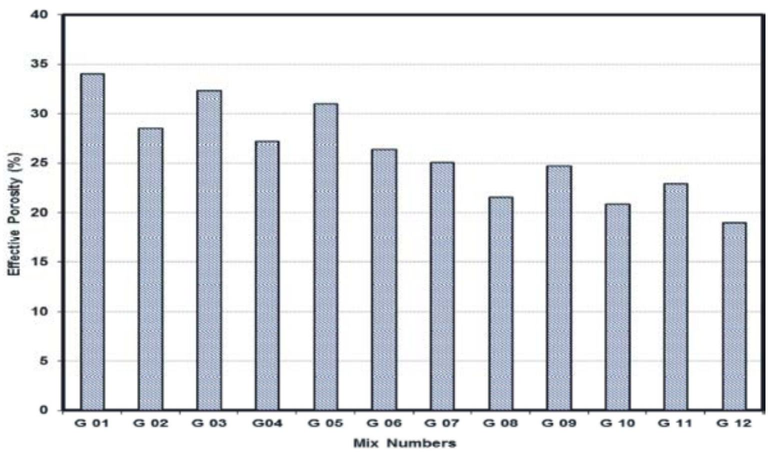

Fig. 5: Effect of mix proportions on effective porosity

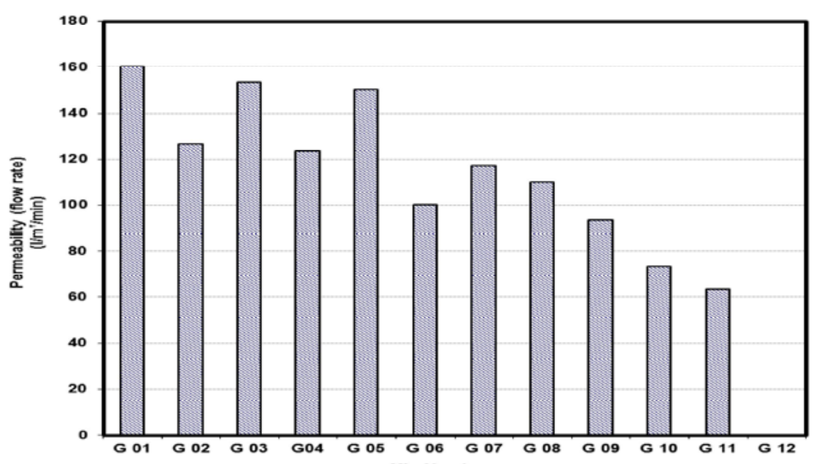

Fig. 6: Effect of mix proportions on permeability

The 28 days flexural strength of the tested mixes ranged from 0.74 MPa to 3.75MPa. The results are shown in Figures 1, 2 and 3, respectively. Photo 2 shows porous concrete specimens.

Density, Effective Porosity and Flow Rate (Permeability): Density was measured at ages 7 and 28 days. The obtained values at 28 days were lower than those obtained at 7 days. This is due to the fact that concrete

Photo 2: porous concrete specimens

loses water with time due to evaporation. The 28 days density ranged between 1.5 tons/m^3 to 1.94 tons/m^3. In-place densities on the order of 1600 Kg/m^3 to 2000 Kg/m^3 are common [24] (Fig. 4). The effective porosity ranged from 19% to 34% pertaining to the tested mixes. Mixes which contained single sized aggregates resulted in higher porosity when compared to mixes of graded aggregates. The increase of cement paste volume had slight effect on porosity. As expected, the inclusion of sand reduced porosity by 7% to 8% in comparison to the mixes in which sand was omitted entirely. The trend of porosity and compressive strength agree with common knowledge that both parameters are inversely related. The aggregate grading exhibited consistent influence on permeability. Mixes produced using single sized aggregates had higher permeability than those produced from graded aggregates. An increase in cement paste volume also reduced permeability but had a much less effect than aggregate grading. Mix 6 yielded flow rate that was 17% lower than the acceptable limit. This result indicates that cement paste/aggregate ratio should not be increased beyond 0.4, in case, graded aggregates are employed. Mixes in which sand were used provided permeability values that were less than the acceptable values. In fact, mix 12 was impermeable. Concerning mixes in which sand was included, the fact that porosity was within the acceptable limits, as opposed to the flow rate. This indicates that sand yielded segmented and partly connected capillary pores. Typical flow rates for water through pervious concrete are 120 lt/m^2/min to 320 lt/m^2/min [24]. Consequently, permeability-wise; sand should be employed as partial replacement of coarse aggregates in percentages less than 10%. Fig. 5 and 6 express the results, respectively.

CONCLUSIONS

Based on the experimental results obtained from this study, the following conclusions can be drawn:

- The standard compaction gave the highest density, while the loose compaction provided the least density concerning the tested specimens.
- All mixes yielded compaction factors that were in the range of 75.8% to 88.3%.
- The use of graded coarse aggregates, the increase of cement paste volume, as well as the inclusion of sand attributed positively to compressive, flexural and splitting tensile strengths.
- The 28 days compressive strength of the tested mixes was within the generally acceptable range
- The effective porosity ranged from 19% to 34% for the tested mixes.
- Mixes which contained single sized aggregates resulted in higher porosity when compared to mixes of graded aggregates.
- Permeability-wise, sand should be employed as partial replacement of coarse aggregates in percentages less than 10%.

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