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Effect of Different Treated Techniques on Palm Oil Fuel Ash to The Physico-Mechanical Properties of Cement Paste

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Abstract

An inquiry is being conducted to explore the potential utilisation of palm oil fuel ash (POFA) in cement concrete due to concerns about the adverse environmental and health consequences associated with its improper disposal. This study investigates the impact of different compositions of POFA (10 wt%, 20 wt%, 30 wt%, and 40 wt%) on concrete qualities when used as a replacement for normal Portland cement (OPC). The objective is to provide pragmatic guidance to analysts and manufacturers that are contemplating the integration of POFA into cement concrete as a means to mitigate apprehensions over environmental contamination. The physical parameters, including water absorption, bulk density, and compressive strength, were assessed using the Mettler Toledo density kit XS64 and a Universal Testing Machine. The findings demonstrate that the concrete containing 40 wt% TPOFA exhibited the lowest bulk density, with an average value of 1.700 g/cm^3. Moreover, there was a constant reduction in bulk density as the concentration of POFA increased. The decrease in POFA content, with the exception of UPOFA, resulted in a reduction in water absorption, indicating an improved ability to resist moisture. The compressive strength increased notably as the TPOFA concentration increased, reaching an average value of 56.88 MPa with the maximum composition of 40 wt%. The enhancement in strength is ascribed to the pozzolanic characteristics of POFA, resulting in a prolongation of the cure period. The study's findings offer useful insights for industry professionals who are looking for sustainable alternatives to OPC. These insights enable the efficient utilisation of POFA in cement concrete applications, while also resolving concerns regarding environmental disposal.

1. Introduction

The construction field is swiftly advancing in this era of technology, bringing forth new technologies and groundbreaking research that holds significant sway over the industry. This progress not only molds the sector but also plays a substantial role in impacting the environment. Crucial construction materials like cement, sand, concrete, bricks, and steel bars are integral to these advancements [1]. Cement, specifically, holds a central position in construction projects globally, but the escalating production of cement raises environmental apprehensions [1]. Hence, exploring alternatives, such as incorporating waste materials in lieu of cement in construction, emerges as a pragmatic approach to tackle environmental concerns. Palm oil fuel ash (POFA) is a tough residue formed by burning husk fiber and palm oil husk in the factory's boiler, producing energy for the palm oil extraction process [2]. Due to its pozzolanic properties, POFA is applied as a partial substitute for cement in different uses [3-5]. Cement paste, identified as a microporous solid with randomly distributed cement gel in an arrangement containing capillary cavities much larger than the gel pores, undergoes testing to optimize the combustion of the raw material. Known as hydraulic cement due to its ability to set and harden underwater, cement can form and solidify even in these conditions. In the absence of contact with soil or groundwater, Standard Portland Cement (OPC) is the most commonly used cement in the production of regular concrete. The strength of Portland cement paste results mainly from the hydration of silicates, with two compounds sometimes termed calcium silicate hydrate being present in the process.

In Malaysia, the integration of Palm Oil Fuel Ash (POFA) into cement is gaining popularity, especially in constructing rigid pavements, as these pavements are deemed flexible enough for such purposes. The significant surge in cement production, driven by the rising demand for modern structures, poses a notable environmental threat due to the substantial emission of CO2 [1]. Moreover, the disposal of POFA, a byproduct of palm oil production in Malaysia, as waste without deriving any benefits, is a common practice [6]. There is an urgent need for further exploration into the extensive use of POFA, particularly in concrete operations. Therefore, this study aims to offer specific guidance to researchers and practitioners using POFA as a partial substitute for standard Portland cement (OPC) in cement concrete. The comprehensive examination will cover both the positive and negative impacts resulting from the utilization of this material. According to the study's objectives, the research aimed to examine the impact of different treated palm oil fuel ash on the physico-mechanical characteristics of cement paste. The specific goals included exploring the ideal composition of cement paste and palm oil fuel ash (POFA) based on physical and mechanical properties. The investigation also aimed to evaluate the strength differences in cement paste incorporating untreated POFA, cement with added treated POFA, and cement with added treated POFA and gravel. Moreover, the study sought to understand how curing times affect the physical and mechanical traits of the samples. The chosen tests for examining the impact on physical properties encompassed water absorption and bulk density, while compressive strength was the focus for evaluating the impact on mechanical properties. When POFA is used in place of 10–40% by weight cement, the concrete retains its strength and is just as durable as OPC concrete. Nonetheless, 30% is the ideal POFA additional content for concrete[15]. Because POFA cement can regulate the expansion of the alkali-silica reaction and external sulphate attack, it has great strength and durability [15]. The goal of the study is to investigate and propose an alternative method for demonstrating how different treated POFA replacements in regular Portland cement could speed up paste setting. The study successfully met its objectives by adhering to the defined research scope and methodology.

2. Material and Method

The raw palm oil fuel ash (POFA) was oven-dried at 900℃ for 24 hours and then the POFA was grinded in a Ball Mills machine for 3 days and sieved using a below 50 microns size to achieve the targeted fineness and remove foreign particles. Then, the POFA were treated in the Gas Furnace at 900°C for 24 hours. For ultrafine treated POFA, the POFA was grinded again in a Ball Mills machine for 1 day. After that, the treated POFA is incorporated into a mixture with the cement and water from 10 wt% to 40 wt% according to Table 1. When POFA is substituted for 10% to 40% by weight cement, the strength and durability of the concrete are maintained, matching that of OPC concrete. However, for concrete, 30% is the optimal POFA extra content[15]. POFA cement exhibits exceptional strength and endurance due to its capacity to control the expansion of the alkali-silica reaction and external sulphate assault [15]. The composition is mixed for 1 minute by using Kakuhunter Planetary Centrifugal Mixer SK-350TII. The mixed samples are demolded after 24 hours and cured continuously for 3 and 7 days. The mixing method was repeated for Ultrafine Treated POFA with cement and the composition of Treated POFA with sand and cement. Cylindrical specimens were used to determine the physical properties such as density and water absorption and also the chemical properties.

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Table 1 *Composition of Cement, POFA, and water for Heated Treated POFA with sand*

Cement (wt%)	Replacement of POFA (wt%)	Water (wt%)	Sand (wt%)
90	10	0.5	0.5
80	20	0.5	0.5
70	30	0.5	0.5
60	40	0.5	

Table 2 *Composition of Cement, POFA, and water for Heated Treated POFA*

Cement (wt%)	Replacement of POFA (wt%)	Water (wt%)
90	10	0.5
80	20	0.5
70	30	0.5
60	40	0.5

Table 3 *Composition of Cement, POFA, and water for Ultrafine Treated POFA*

Cement (wt%)	Replacement of POFA (wt%)	Water (wt%)
90	10	0.5
80	20	0.5
70	30	0.5
60	40	0.5

2.1 Calculation of Water Absorption Testing

The evaluation of water absorption in a hardened sample is done through the cold-water technique after 3 and 7 days of curing [3]. This process involves comparing the specimen's mass in water to its mass in the air to assess how much water it absorbs. The aim is to observe changes in the material's properties at different points during the curing process

$$Water\ Absorption = \frac{W_w - W_d}{W_w} \times 100\% \quad (1)$$

2.2 Calculation of Compressive Strength

In this study, the testing apparatus for measuring compressive strength has a maximum capacity of 10KN, and it utilizes a Universal Testing Machine. The determination of compressive strength involves calculating the compressive strength of the cylindrical samples. All samples undergo testing, and their collective average is considered as the ultimate compressive strength. The formula used for this calculation involves the variables σi (compressive strength), Fi (maximum load), and Ai (cross-sectional area where the load is applied).

$$\delta_i = \frac{F_i}{A_i} \quad (2)$$

2.3 Calculation of Bulk Density Testing

Bulk density was determined through a method grounded in Archimedes' principle. The weight values, crucial for the computation of bulk density, were recorded using the density kit. This process was carried out for various compositions of palm oil fuel ash (POFA), as outlined in equation (3).

$$Pb = \left(\frac{Wd}{Ww - Ws} \times (\, Pw - P(\, air) + Pair) \right) \quad (3)$$

3. Result and Discussion

3.1 Water Absorption of The Cement

The capacity of cement paste to absorb water is one of its inherent physical qualities. Fig. 1 and Fig. 2 depict the water absorption rates at various curing durations for different compositions of POFA replacement. The water absorption is found to decrease when the composition of POFA replacement varies at different curing durations. The absorption of water is a significant factor that affects the durability of the sample. Based on the graph, the samples with a composition of 10 wt% POFA (TPOFA: cement: water) have a curing period of 3 days and 7 days, resulting in percentages of 54.73% and 55.59% respectively. The reason for this is because the cement undergoes shrinkage throughout the 7-day curing period, resulting in the development of tensile strains inside the cement. Consequently, the samples may experience surface cracking after 7 days of curing, rather than 3 days, particularly if the stresses arise before the concrete reaches sufficient tensile strength. Moist curing was consistently maintained during the whole 7-day curing period to ensure a damp environment. If this is unattainable, it is imperative to shield the cement surfaces from desiccation. The results indicate that the water absorption levels of the samples were exceptionally high. Typically, high-quality cement has a water absorption rate of less than 5% [7,8]. The low water absorption was primarily achieved because to the cement's low permeable porosity. This can be due to the enhanced water absorption of POFA, as the POFA used in this study has a larger surface area compared to cement. In addition, the POFA cement exhibits higher permeability and contains a greater amount of unground POFA. Regardless, the cement may not have an adequate curing period for the hydration process, which hampers densification due to reduced by-product formation and increases the presence of pores within the concrete. The water assimilation occurs due to the capillary effect of pores [9,10].

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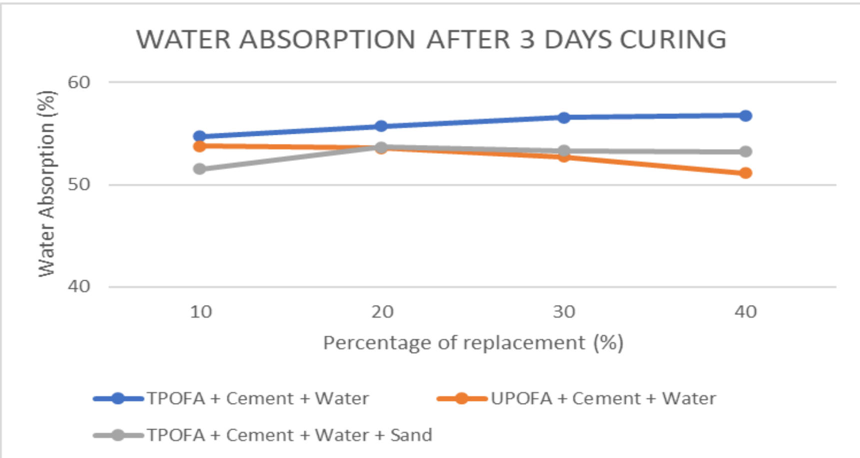

Fig. 1 *The percentage of water absorption based on different POFA composition in 3 dayscuring time*

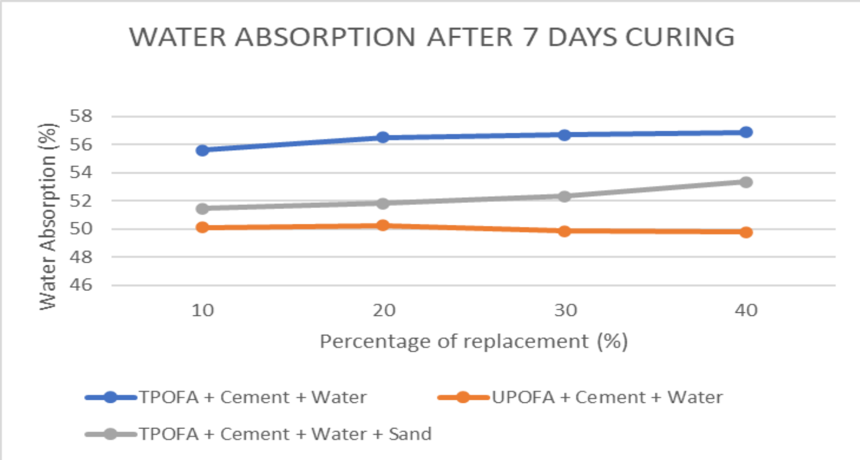

Fig. 2 *The percentage of water absorption based on different POFA composition in 7 days curing time*

3.2 Bulk Density of The Cement

Fig. 3 and Fig. 4 demonstrate a decrease in the bulk density of the cement paste as the substitution of POFA increased. The analysis revealed that the composition TPOFA, with a weight percentage of 40%, exhibited the lowest bulk density, averaging at 1.7637 gcm−3. This could be attributed to the amplified quantity of cement resulting from the identical mass replacement of ordinary Portland cement (OPC) with TPOFA. The typical range for the average density of a regular cylindrical object is from 2.000 g/cm^3 to 2.300 g/cm^3. When the proportion of POFA replacement reached 10 wt% and 40 wt% (TPOFA: cement: water) throughout the 3-day curing period, the average density reduced to 0.0713 gcm−3. This phenomenon occurs frequently because the bulk density can drop as a result of the lower specific gravity (SG) of POFA compared to cement, and the potential for POFA to trap air bubbles [11]. Furthermore, the inclusion of 40 wt% treated POFA resulted in a more steady performance during the heating phase in the reference cement paste tests. The outcome indicated that the bulk density was affected by the duration of the curing process. The formation of these phases can occupy the empty spaces and obstruct the materials in the stabilised cement, resulting in a reduction in water absorption and an increase in bulk density. Nevertheless, the utilisation of ultrafine POFA (UPOFA) in the research demonstrates that the samples were more compact due to the decreased weight and specific gravity of UPOFA compared to OPC [12].

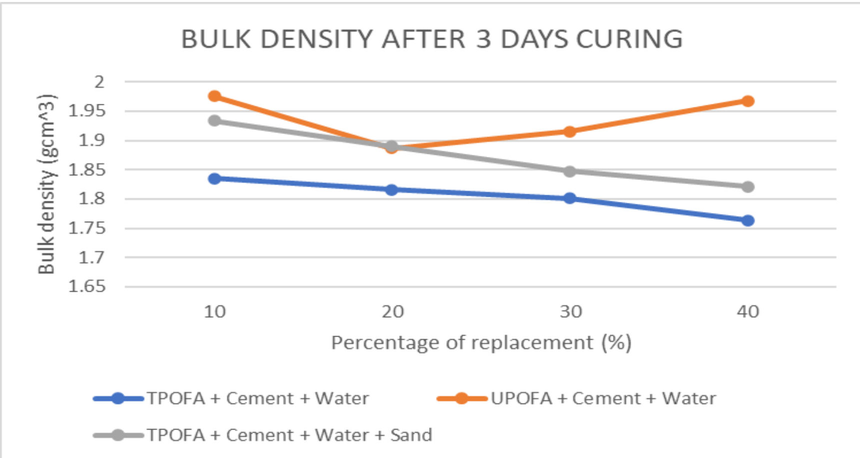

Fig. 3 *The bulk density based on different POFA composition in 3 days curing time.*

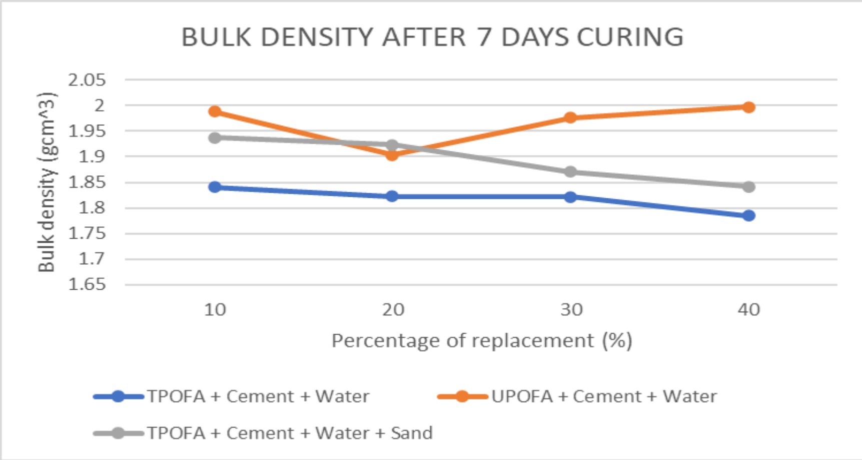

Fig. 4 *The bulk density based on different POFA composition in 7 days curing time*

3.3 Compressive Strength of The Cement

The mechanical characteristics of cement are intricately linked to its ability to withstand compression, making it a valuable tool for classifying and identifying the features of a given sample. The technique employed to investigate the mechanical properties of cement with the replacement of palm oil fuel ash (POFA) is focused on measuring compressive strength. As the amount of POFA used as a replacement grew, the compressive strength also increased gradually. The composition of treated POFA (TPOFA) exhibits greater compressive strength compared to ultrafine POFA (UPOFA) and treated POFA mixed with sand.

Fig. 5 illustrates the gradual rise in the composition of the POFA (TPOFA: cement: water) from 10 wt% to 40 wt% as a substitute for the POFA. This results in an increase in strength from 22.3 MPa to 45.03 MPa. Meanwhile, the POFA composition (UPOFA: cement: water) shows a modest improvement in strength, ranging from 25.94 MPa to 30.32 MPa, as the replacement of POFA ranges from 10 wt% to 40 wt%. In conclusion, a curing period of 3 days effectively decreases the evaporation of water from the surface of the cement samples.

Meanwhile, Fig. 6 displays the compressive strength after 7 days of curing period. The purpose of the 7-day period is to avoid or restore the loss of moisture from the cement and also to maintain a favourable temperature for hydration to take place. The compressive strength of cement is maximised when a membrane-forming component is used during the curing process for a duration of 7 days [12]. The substitution of POFA (TPOFA: cement: water) resulted in an increase in pressure from 37.54 MPa to 61.88 MPa when the POFA content was increased from 10% to 20%. However, the graph showed no further changes once the POFA content reached 20%. The compressive strength of the POFA composition (TPOFA: cement: water: sand) exhibited an increase from 30 wt% to 40 wt%, ranging from 24.10 MPa to 24.78 MPa. There was a minor and consistent decline observed from 22.45 MPa to 23.88 MPa. Meanwhile, the content of ultrafine POFA experiences a modest increase as the substitution level rises from 10 wt% to 40 wt%. Hence, the compressive strength of the POFA varied when the replacement of POFA was altered.

This indicates that the compressive strength of the samples in the cylindrical instances rose as the POFA substance grew, along with an increase in the curing time period. These findings are consistent with the results of previous studies[14]. The potential replacement of the regional mixture with the POFA is reduced as the applied force on it is increased. This phenomenon can be attributed to the elevated porosity of POFA particles, resulting in increased water absorption, expansion of empty spaces, and reduction in the compressive strength of pervious concrete [13]. The presence of calcium oxide (CaO) and K2O in POFA can lead to the creation of pores and a decrease in compressive strength [14]. The superior quality execution of POFA compared to Ordinary Portland Cement (OPC) concrete may be attributed to the much higher degree of fineness of POFA, which enhances its pozzolanic property. This phenomenon may occur as a result of the evaporation of the water necessary for the process of hydration into the surrounding environment.

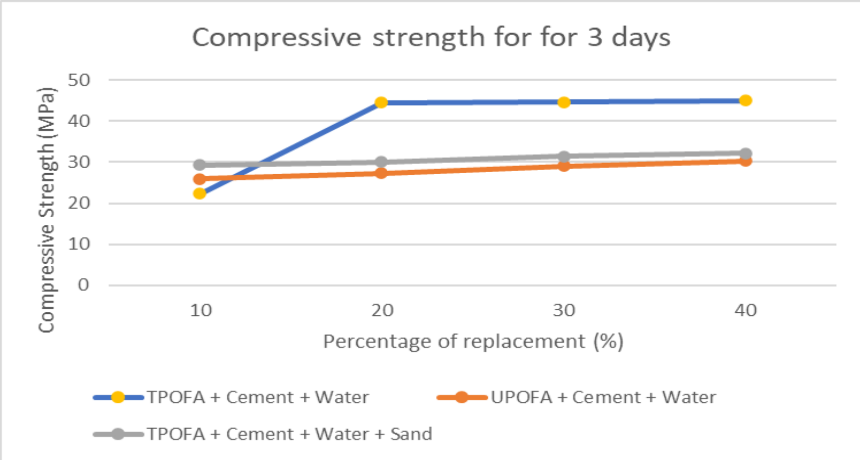

Fig. 5 *The compressive strength of the cement based on different POFA composition at 3 days curing time*

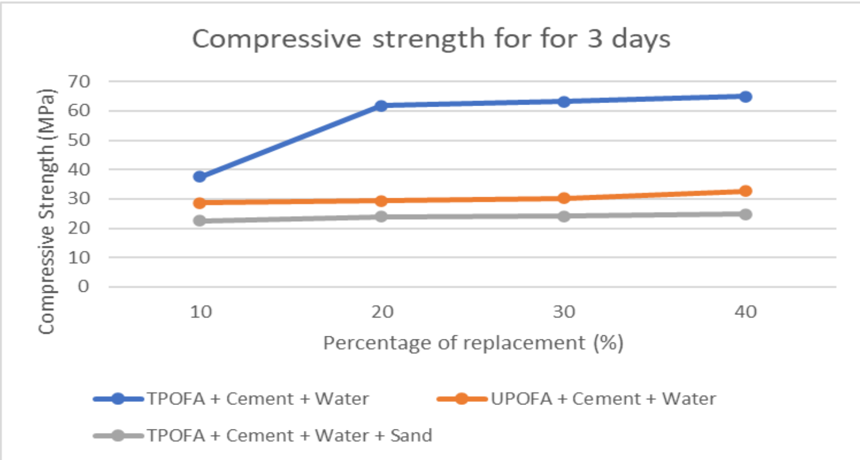

Fig. 6 *The compressive strength of the cement based on different POFA composition at 7 days curing time*

4. Conclusion

From the experimental results and discussion, it can be concluded that increasing the content of POFA in the sample has an impact on both the physical and mechanical properties of the sample, as well as the duration of the curing period. Because of its larger bulk density and surface area, ultrafine POFA absorbs less water than heated treated POFA. In contrast to ultrafine POFA, heated treated POFA has a greater compressive strength. The water absorption was shown to significantly decrease with the replacement composition of UPOFA. In addition, the average bulk density of the cement paste dropped as the substitution of TPOFA and (TPOFA with cement and sand) rose, as a result of the increased volume of cement when replacing the same mass of ordinary Portland cement (OPC) with POFA. The duration of the curing process has an impact on the compressive strength. Research has revealed that a longer duration of curing results in increased compressive strength due to the enhanced polymerization process that occurs during this period [16].

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design, data collection, methodology, analysis and interpretation of results:*** *Amirul Hafiz Sabari and Mohamad Zaky Noh. All authors reviewed the results and approved the final version of the manuscript.*

Appendix

Curing time	Sample	Percentage of replacement (%)	Water Absorption (%)	Bulk Density (g/cm^3)	Compressive Strength (MPa)
3 Days	TPOFA + Cement + Water	10	54.73	1.8350	22.30
		20	55.69	1.8160	44.50
		30	56.55	1.8010	44.67
		40	56.75	1.7637	45.03
	UPOFA + Cement + Water	10	53.78	1.9760	25.94
		20	53.56	1.8870	27.34
		30	52.71	1.9150	29.11
		40	51.11	1.9678	30.32
	TPOFA + Cement + Water + Sand	10	51.53	1.9340	29.34
		20	53.65	1.8898	30.10
		30	53.34	1.8470	31.45
		40	53.21	1.8210	32.14
7 Days	TPOFA + Cement + Water	10	55.59	1.8410	37.54
		20	56.52	1.8230	61.88
		30	56.71	1.8213	63.13
		40	56.88	1.7850	64.98
	UPOFA + Cement + Water	10	50.12	1.9880	28.67
		20	50.25	1.9034	29.35
		30	49.85	1.9760	30.26
		40	49.77	1.9967	32.68
	TPOFA + Cement + Water + Sand	10	51.45	1.9370	22.45
		20	51.83	1.9230	23.88
		30	52.35	1.8710	24.10
		40	53.37	1.8413	24.78

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