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Green Building: Use of Pozzolanic Material to Reduce CO_2 Emissions and Energy Conservation in the Production of Composite Pozzolanic Cement

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Abstract: The effect of pozzolanic material on the mechanical properties and microstructure of clinker Portland cement mortar was studied. The main objective of this research is to formulate a Pozzolanic blended cement mortar with high mechanical properties to reduce CO_2 emissions and energy conservation uses in the clinker industry. The present investigation aims to study the effect of fresh basalt on the properties of clinker and Portland cement pastes. The rate of hydration was studied from the determination of free lime and combined water up to 90 days of hydration. The physical-mechanical properties such as compressive strength, phase composition, and microstructure of mortar were investigated. The results revealed that the water consistency increased with the basalt substance while the setting time was somewhat elongated. On the other hand, the combined water increases with the basalt content and curing time. This can be primarily due to the influence of nucleating of basalt as a filler in pozzolanic cement generation. The fresh mortar pastes were first cured at 100% relative humidity for 24 h and then cured in water for 90 days. The results showed that the compressive strength of the cement mortars with basalt pozzolanic mixed cement was higher than plain clinker Portland cement mortar; the improvement in compressive quality was 10% to 15% basalt.

Keywords: Clinker Portland Cements Mortar (CPC), Basalt, Phase Composition, Microstructure, Basalt Pozzolanic Blended Cement, Green Building, Durability, Sustainable, CO_2 Emission, Energy Conservation, Hydrated, Compressive Strength and XRD

Introduction

Pozzolana is a material capable of reacting with $Ca(OH)_2$ in the presence of water at room temperature to form cementitious compounds (as C-SH gel). Basalt is an igneous rock, which was formed during the cooling of magma in the additional years of the earth's history. In recent years, many articles have established that the use of supplementary cementitious materials like fly ash, blast furnace slag, silica fume, metakaolin pozzolana, rice husk, basalt, etc. can not only improve the various properties of concrete both in its fresh and hardened states, but can also pay for the economy in construction costs. So various cementitious materials are added to obtain the concrete with the desired property. (Ghrici *et al*., 2007; Plank and Winter, 2008; Zhou *et al*., 2016), metakaolin at a 10% concentration. The replacement level considerably increases chloride binding compared to that of common Portland pozzolana cement. Clay minerals' particular properties, such as metakaolin at 10% replacement level, significantly increase chloride binding compared to that of common Portland pozzolana cement. Clay minerals' particular properties, such as electric charge (cationic and anionic clay minerals), dynamic locales and functional bunches in clay mineral surfaces, fundamental basic units, planar and non-planar structures, and orderly clay minerals such as basalt, are presented and examined. The one-of-a-kind properties of certain clays and clay minerals legitimize their uses for both intimate and outer applications (Muralidharan *et al*., 2021). Basalt may be a liquid shake with under 20% quartz and beneath 10% feldspathoid by volume and where no less than

65% of the feldspar is as plagioclase. Basalt highlights a cleaned organism scattered with minerals. It has excellent pozzolanic properties and produces higher quality when mixed with cement, and it is commonly used in construction (Asadi *et al*., 2017; Binici *et al*., 2012). (MacFarlane, 2021), reported that the use of cement replacement material may reduce the factors related to declining concrete durability or improve its resistance against sulphate attack. In addition to natural or industrial by-products, pozzolanic cement contains clinker Portland cement as one of its main components. Slag, fly ash, home, silica fumes, rice husk ash, and other wastes are examples (Gomes and Rautureau, 2021).

Basalt as a mineral admixture was investigated, where the physical properties and chemical compositions were studied (Zhou *et al*., 2016; Binici *et al*., 2008). The effect of basaltic pumice on the mechanical and physical properties (Keleştemur and Demirel, 2010) and the seawater resistance of the concrete were studied (Binici *et al*., 2008). Also, the deterioration effect of blended cement combinations with Red Brick Dust (RBD) and Ground Basaltic Pumice (GBP) was investigated (El-Desoky *et al*., 2021). This study is aimed at investigating the influence of basalt up to 15% on the physicochemical characteristics of cement pastes to produce the pozzolanic cement product.

Methods Experimental

The Aim of the Study

The present aims to ponder the effect of basalt as a pozzolanic substitution of clinker Portland cement rate to produce pozzolanic cement and reduce CO2 emissions and energy management in composite cement production by reducing the clinker factor.

Materials and Experimental Techniques

Materials

Clinker Portland Cement (CPC), delivered by Lafarge Holcim Cement Company, Egypt, Its chemical analysis obtained is given in Table 1 showing that it was a good clinker. The fresh basalt from Zafarana, Egypt, and the reactive silica content is 20%, which has a positive impact on the hydration results of cement products; the oxide composition of basalt is summarised in Table 2. The Blaine surface area of basalt pozzolanic cement was 4000 cm 2/g. The strength enhancer from Naval Egypt Company, the exchange name is MA.G.A/C129, was used as a fine aggregate in the mortar investigated using XRD and ATA techniques.

Table 1: CPC chemical oxide analysis (mass, %)

Oxides	Mass %
SiO_2	21.4000
$Al2O_3$	4.5000
$Fe2O_3$	4.7400
CaO	64.2600
MgO	3.1300
SO3	1.3800
K_2O	0.3800
Na_2O	0.6200
F.L	0.1000

Table 2: Chemical oxide analysis of basalt with (mass, %)

Oxides	Mass %
SiO_2	46.360
$Al2O_3$	13.840
$Fe2O_3$	12.690
CaO	11.270
MgO	6.760
SO_3	0.290
K_2O	0.700
Na_2O	2.940
CL	0.100
L.O.I	3.050

Experimental Techniques

CPC was mostly substituted with basalt up to 15.0 mass, % included 5 mass, % fixed gypsum for all mixes, and strength enhancer was included with a dosage of 900 gm/ton. Each dry mix was mixed for 4.0 h using a steel ball method to achieve total homogeneity and a wide surface range. The paste was physically positioned, squeezed, and homogenized in stainless steel molds. After the top sheet was compacted, the best surface of the form was smoothened with the help of a thin framed trowel. The consistency of the water and the beginning, as well as final setting times, was gritty. The chemically joined water content was determined by the start of the paste at 950°C for one hour, the free lime, and the compressive strength. Were determined. The hydration mortar was, moreover, taken over with the aid of DTA.

Production of Pozzolanic Cement

Clinker Portland cement was replaced with different percentages of basalt as shown in Table 3. The hydration characteristics of Pozzolanic blended cement pastes were determined by determining water of standard consistency (w/c, %), setting times, chemically combined water (Wn), and free lime. The compressive strength was measured on cement mortars. Also, the hydration yields were identified using DTA techniques.

Results

The Water of Consistency and Setting Times

The water consistency (w/c. %) as well as the Initial and Final Setting Times (IST, FST) of the examined pastes are assumed in Table 4 and graphically represented in Fig. 1.

Table 3: Mix composition of pozzolanic CPC

Mix no.	M1	M2	M3	M4
CPC	95	90	85	80
Basalt	0	5	10	15
Gypsum	5	5	5	5

Table 4: The basalt-pozzolanic blended cement pastes' water of consistency % and setting times (min) setting times (min)

Mix no.	The water of consistency, %	F.ST	I.ST
M1	25.2	150	205
M2	26.8	155	215
M3	27.8	160	245
M4	30.0	165	280

Table 5: Combined water contents (Wn. %) of hydrated CPC-basalt pozzolanic blended cement pastes with curing time

Time, days / Mix no.	2	7	28	90
M1	12.3	17.0	19.5	23.88
M2	12.1	21.0	24.0	25.90
M3	12.2	22.0	25.1	26.20
M4	12.0	17.1	20.5	25.90

Table 6: Free lime contents of CPC and basalt-pozzolanic cement pastes with curing time, wt. %

Time, days Mix no.	2	7	28	90
M1	9.5	12.1	13.6	14.9000
M2	9.0	9.2	8.4	6.43000
M3	8.9	8.5	8.9	5.26000
M4	8.7	8.5	8.7	6.30000

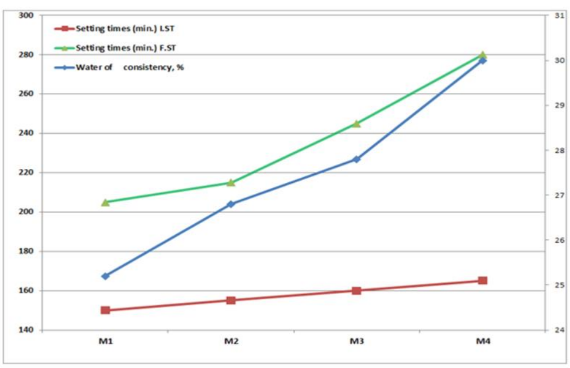

Fig. 1: Water of consistency % and Initial and final setting times (min) of basalt-pozzolanic cement pastes

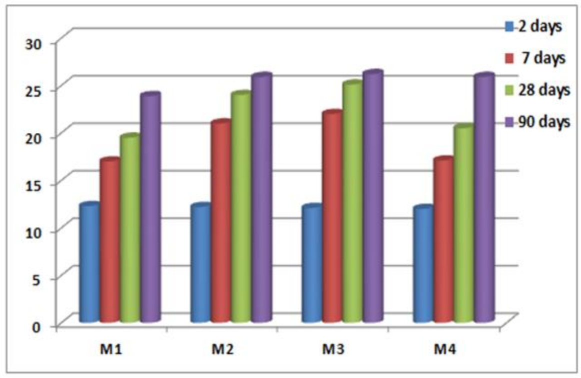

Fig. 2: Combine water contents (Wn. %) of hydrated basalt-pozzolanic cement with curing time up to 90 days

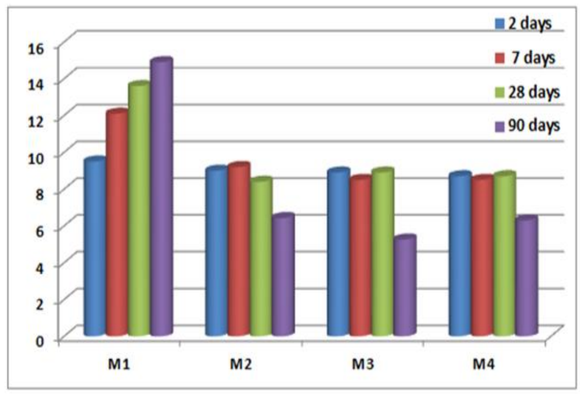

Fig. 3: Free lime contents wt. %, of hydrated basalt-pozzolanic cement pastes up to 90 days

Chemically Combined Water Contents (Wn. %)

The variety of Wn. % of the hydrated basalt-pozzolanic blended cement as well as CPC with drying time up to 90-days and basalt substances are recorded in Table 5 and graphically designed in Fig. 2. The values of combined water increment with curing time for all cement pastes.

Free Lime Contents

The free lime matters of CPC and basalt Pozzolanic Cement-filled cement pastes cured for 3, 7, 28, and 90 days are recorded in Table 6 and plotted as a function of curing time up to 90 days in Fig. 3.

Compressive Strength

The compressive strength data of CPC in addition to pozzolanic cement mortars cured for up to 90-days are exposed in Table 7. These results are graphically embodied as a role of curing time in Fig. 4.

Table 7: Compressive strength values of CPC and basalt-pozzolanic cement mortars with curing time, MPa

Time, days Mix No.	200	700	280	90
M1	200	330	44.5	48
M2	190	340	43.1	55
M3	18.3	32.2	42.9	58
M4	170	32.8	46.8	57

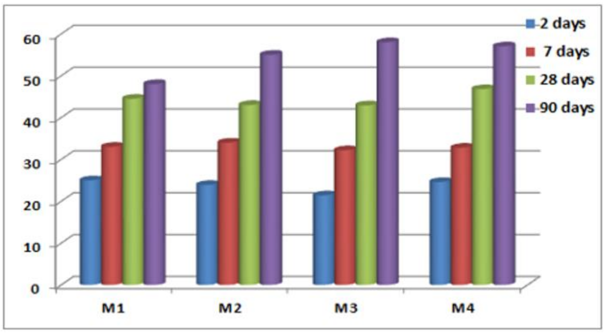

Fig. 4: Compressive strength values of CPC and basalt pozzolanic cement mortars with curing time, MPa

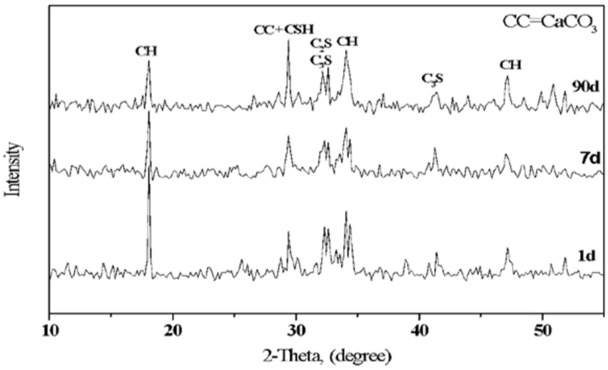

Fig. 5: XRD diffract grams of hydrated CPC-basalt-pozzolanic cement paste with curing time

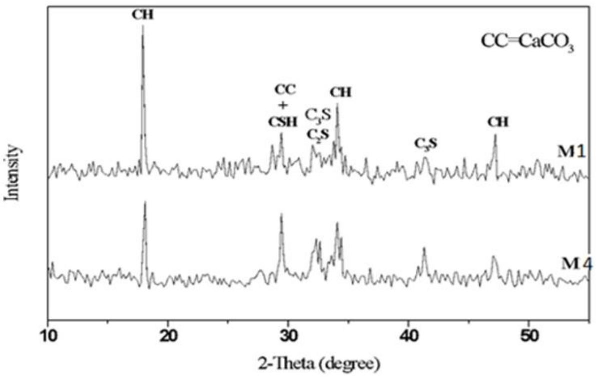

Fig. 6: XRD patterns of hydrated, CPC (M1), and 15% basalt-Pozzolanic cement pastes at 7 days

XRD Analysis

The influence of curing time up to 90-days on the hydration characteristics of Pozzolanic mixed Cement containing 15% mass of basalt can be realized from XRD patterns in Fig. 5.

The XRD patterns of hardened CPC (M1) and 15 mass % basalt pozzolanic cement pastes, % basalt (M4) at 7 days of hydration are shown in Fig. 6.

Discussion

The Water of Consistency and Setting Times

The water consistency (w/c. %) as well as Initial and Final Setting Times (IST, FST) seem to indicate that the pozzolanic blended cement needs higher water requests and lengthy Setting Times (STs) compared with the CPC. Furthermore, with Basalt pleased, w/c. % and STs are increased. This can be mostly due to the higher surface area of basalt pozzolanic cement than CPC, as specified above. The impediment of setting handle and stretching of setting times may be due to the lessening of the cement clinker percentage (dilution impact), creating CSH, which has greater setting characteristics (Keleştemur and Demirel, 2010) in evaluation with basalt pozzolanic cement glues.

Moreover, the slight pozzolanic movement of basalt may unfavourably influence the setting handle of basalt-pozzolanic motley cement pastes. So cement pastes holding 5 wt.% of basalt tend to shorten the initial setting time more than pure cement paste. This is usually due to the nucleating control, which fast-tracks the rate of cement hydration. As the amount of basalt rises to 15 wt. %, the starting setting time is in a stretched mode. This is mainly due to the attenuation effect of the clinker and the low degree of hydration of basalt Pozzolanic blended cement in appraisal with CPC.

The final setting time of basalt-pozzolanic blended cement pastes extends with the amount of basalt. This is essentially due to the decrease of the formed CSH gel in the early days and the dilution of the cement content. The hydration of cement is faster than the pozzolanic reaction of basalt with portlandite (El-Desoky *et al*., 2021; Dobiszewska, 2017; Dobiszewska *et al*., 2019, El-Didamony *et al*., 2015).

Chemically Combined Water Contents (Wn. %)

The variety of Wn. % of the hydrated basalt-pozzolanic blended cement as well as CPC with drying time up to 90-days. The values of combined water increase with curing time for all cement pastes, due to the nonstop hydration of cement phases and pozzolanic response, leading to the organisation of hydrated aluminates, silicates, and aluminosilicates with high water content (Vickers *et al*., 2015). On the other hand, basalt cement pozzolanic cement has higher values of Wn compared to the control (CPC) by up to 10%. Moreover, the sum of wine increments with basalt substance up to 10% and then diminishes at 15%. Typically primarily ascribed to that; the basalt test operated in this study is primarily composed of crystalline phases such as quartz and mullite in growth to amorphous materials such as reactive silica. And the part of the strength enhancer in this way has pozzolanic activity, which increases the hydration representative.

Hence, the combined water content (Wn. %) increases as the combined water content of basalt pozzolanic cement paste increases, with curing time. Due to that, the CSH made has a pozzolanic reaction (Brew and Glasser, 2005; Khudyakova *et al*., 2020). It can be detected that the combined water content increases regularly with curing time for all hardened cement pastes due to the development of hydration. At all curing ages, basalt-filled cement pastes have a higher combined water content than ordinary Portland cement pastes. Also, as the basalt content increases, the chemically combined water content decreases. This is mainly due to pozzolanic activity. Therefore, the combined water content reduction with the amount of Portland cement, which is the main factor in the hydration of pozzolanic cement pastes. It has excellent pozzolanic properties and, when combined with clinker, provides advanced strength as well as a strength enhancer and is commonly used in development exercises (Asadi *et al*., 2017; El-Didamony *et al*., 2016).

Free Lime Contents

It is clear that the free lime content rises with curing time for all cement pastes in CPC but drops for basalt pozzolanic cement pastes. This means that the basalt has pozzolanic action and it behaves as filler. Therefore, this type of cement is called pozzolanic or filled-cement. The free lime content of all cement increases after two days; this is primarily due to the nucleating effect of the basalt, which accelerates the rate of hydration of cement pastes. Clinker cement pastes release more hydrated lime than pozzolanic cement paste. As the quantity of basalt increases at the expense of clinker Portland cement up to 15%, the liberated lime decreases for all curing times up to 90 days. At 15 wt % basalt, the free lime is less than that of 10 wt % basalt up to 28 days. This is mainly due to the reduction of the volume of clinker Portland cement, which is the main source of liberated lime. There is a decrease in free lime content of the occupied cement pastes containing basalt up to 15 wt % after 90 days. This could be due to basalt's pozzolanic activity at most hydration ages, caused by the growth of OH-ions at later ages from the liberated $Ca(OH)_2$. Saraya (2014), Abdelaziz *et al*. (2014), Khalil (2016), and Heikal *et al*. (2020). The initial increase of free lime in pozzolanic cement is mainly due to the basalt hydration of the clinker. As basalt content increases, the liberated portlandite decreases, due to the nucleating agent along with the very low pozzolanicity of basalt at one day. The rise of basalt content tends to separate the hydrated CSH-gel, which improves the liberation of portlandite. The lessening after 2 days is due to the depletion of basalt. There are two different progressions; one tends to increase the portlandite and the other tends to decrease its rate due to the pozzolanic response. This purpose of free lime content is more significant for the demonstration of the pozzolanic properties of basalt. It provides some suggestions on the progress of the pozzolanic reaction. These findings are consistent with previous findings that the basalt begins to react with $Ca(OH)_2$ between 2 and 7 days, but significant amounts of $Ca(OH)_2$ and basalt motionless remain unreacted for up to 90 days of hydration. Therefore, it can be concluded that this basalt is a pozzolanic material. Both the free lime and combined water content of basalt-Pozzolanic blended cement pastes are less than those of CPC pastes. This may be accredited to the low pozzolanic motion of basalt, at early ages of hydration (Dedeloudis *et al*., 2018).The benefits of using specific pozzolan resources as strength enhancers in cement and concrete are obvious in terms of higher compressive strength, extended concrete permanence, lower heat of hydration, reduced dying, and others (Kunther *et al*., 2017).

Compressive Strength

These results show that the compressive strength increases with curing time for all hardened cement mortars. More hydration products and cementing materials are manufactured as hydration earnings rise. This is central to an increase in the compressive strength of hardened cement mortars. This is mainly attributed to the fact that hydration products possess a larger specific volume than unhydrated cement. As a result, the accumulation of these hydration products will block a portion of the available pore spaces, allowing for generous higher strength. On the other hand, as the basalt content increases, the compressive strength decreases in primary time but increases in late time, as observed elsewhere (Binici *et al*., 2014; Ashish, 2018). This is often due to the lower pozzolanic action of the basalt-particles but is often increased by a strength enhancer. In expansion, the decay reactions of the glassy phase of the basalt would be moderated. Hence, these components weaken the structure of the hardened pastes, so that their strength is diminished. The compressive strength was in accordance with the free lime. Moreover, the compressive strength values are in excessive agreement with those of the combined water content. The increase in hydration items

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is the most important factor in compressive strength. This may be due to the diminution of the liberated lime as it performed from the comet with free lime content. The growth of free lime drops the compressive strength. In comparison to CSH, free lime has an extremely low strength (Mokhtar *et al*., 2021; Basu *et al*., 2021; Singh *et al*., 2017; Cheah *et al*., 2019, Pham, 2020).

XRD Analysis

The influence of curing time up to 90-days on the hydration characteristics of pozzolanic mixed cement containing 15% mass. It is clear that the characteristic peak of CSH increases, while the peaks of portlandite (CH) decrease with curing time. Typically, this is due to the pozzolanic response of the basalt percentage with the liberated lime, forming extra amounts of CSH. The rate of basalt pozzolanic reaction with lime grows with time. In this manner, the rate of lime utilisation surpasses the rate of its generation. The behaviour of CH peaks is in agreement with the results of chemically determined free lime. Moreover, the XRD patterns act in a $CaCO_3$ peak that increments with curing age, due to the increment of portlandite, which is accessible for carbonation with air CO_2 (El-Didamony *et al*., 2020; Saraya, 2011; Diab *et al*., 2021).

Hardened CPC (M1) and 15% basalt pozzolanic cement paste XRD patterns after 7 days of hydration. The results seem to be the nearness of un-hydrous silicates (β-C2S and C3S), Calcium Hydroxide (CH), Calcite (CC), and Calcium Silicate Hydrate (CSH). The presence of 15 % of basalt with Portland cement diminishes the amount of CPC. Moreover, the utilised basalt has low pozzolanic activity, particularly at early hydration ages. Hence, the intensity of CSH and CC peaks in CPC pastes is lower than the comparative peak in basalt blended cement pastes. Calcium hydroxide carries on in an inverse way to CSH.

The peak of anhydrous silicate losses with the nearness of basalt, due to the reduction of clinker phases with 15% mass basalt. The intensity of the Portlandite peak is in agreement with that of a chemical inspection (Malkawi *et al*., 2017; Veronika and Zuzana, 2014; Moehmel *et al*., 2001).

Conclusion

The influence of curing time up to 90-days on the hydration characteristics of pozzolanic mixed cement containing 15% mass. It is clear that the characteristic peak of CSH increases, while the peaks of portlandite (CH) decrease with curing time. Typically, this is due to the pozzolanic response of the basalt percentage with the liberated lime, forming extra amounts of CSH. The rate of basalt pozzolanic reaction with lime grows with time. In this manner, the rate of lime utilisation surpasses the rate of its generation.

The main conclusions derived from this study may be summarised as follows:

- By substituting up to 15% basalt in cement clinker production, we can reduce CO2 emissions and energy consumption in the clinker industry
- Basalt pozzolanic cement pastes require more water for mixing than CPC pastes
- Basalt pozzolanic cement has little pozzolanic activity at first but grows with time and has a strength enhancer effect
- Basalt pozzolanic cement with a strength enhancer has superior physicomechanical properties to CPC cement paste
- Basalt pozzolanic cement construction is both environmentally safe and cost effective
- The assimilation of a basalt mixture in a concrete mix affects the compressive strength of basalt blended cement
- Maximum compressive strength was achieved by 10-15% additional cement by a mixture of basalt at 90 days of curing
- Basalt can be used as a filled-pozzolanic material to produce pozzolanic cement, which is now produced by Lafarge Cement Egypt under the name pozzolanic cement

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Author's Contributions

Abd EL-Rahman Ragab: Designed the research plan, organized the study, did some analysis, wrote the manuscript and interpreted the data and reviewed it.

Shimaa Younis and Mohamed Sayed Mohamed Moawad: Work participated in all experiments, coordinated the data-analysis.

Ethics

"Conflict of Interest: The authors declare that they have no conflict of interest."

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