American Journal of Engineering Research (AJER)
e-ISSN : 2320-0847 p-ISSN : 2320-0936
Volume-02, Issue-05, pp-55-60
www.ajer.us

Research Paper Open Access

Strength of Blended Cement Sandcrete & Soilcrete Blocks Containing Cassava Waste Ash and Plantain Leaf Ash

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Abstract: This work investigated the compressive strength of binary and ternary blended cement sandcrete and soilcrete blocks containing cassava waste ash (CWA) and plantain leaf ash (PLA). 135 solid sandcrete blocks and 135 solid soilcrete blocks of 450mm x 225mm x 125mm were produced with OPC-CWA binary blended cement, 135 with OPC-PLA binary blended cement, and 135 with OPC-CWA-PLA ternary blended cement, each at percentage OPC replacement with pozzolan of 5%, 10%, 15%, 20%, and 25%.Three sandcrete blocks and three soilcrete blocks for each OPC-pozzolan mix and the control were crushed to obtain their compressive strengths at 3, 7, 14, 21, 28, 50, 90, 120, and 150 days of curing. Sandcrete and soilcrete block strengths from binary and ternary blended cements were found to be higher than the control values beyond 90 days of hydration. The 150-day strength values for OPC-CWA-PLA ternary blended cement sandcrete and soilcrete blocks were respectively 5.90N/mm^{2}and 5.10N/mm^2 for 5% replacement, 5.80N/mm^{2}and 4.95N/mm^2 for 10% replacement, 5.65N/mm^{2}and 4.85N/mm^{2}for 15% replacement, 5.60N/mm^{2}and 4.75N/mm^{2}for 20% replacement, and 5.25N/mm^{2}and 4.65N/mm^2 for 25% replacement; while the control values were 5.20N/mm^2 and 4.65N/mm^2. Thus, OPC-CWA and OPC-PLA binary blended cements as well as OPC-CWA-PLA ternary blended cement could be used in producing sandcrete and soilcrete blocks with sufficient strength for use in building and minor civil engineering works where the need for high early strength is not a critical factor.

Keywords: *Binary blended cement, ternary blended cement, sandcrete block, soilcrete block, pozzolan, cassava waste ash, plantain leaf ash.*

I. INTRODUCTION

Sandcrete and soilcrete blocks are cement composites commonly used as walling units in buildings all over South Eastern Nigeria and many other parts of Africa. Many researchers have investigated various aspects of these important construction materials. Baiden and Tuuli (2004) confirmed that mix ratio, materials quality, and mixing of the constituent materials affect the quality of sandcrete blocks. Afolayan, Arum, and Daramola (2008) tested the compressive strength values of sandcrete blocks produced by different block industries in Ondo State, Nigeria and found that they were very much lower than those stipulated by the relevant Codes and Standards. The blocks also had high coefficient of variation that indicate very poor quality control in the production processes. Wenapereand Ephraim (2009) found that the compressive strength of sandcrete blocks increased with age of curing for all mixes tested at the water-cement ratio of 0.5. The strength at ages 7, 14, and 21 days were 43%, 75%, and 92% of the 28-day strength respectively. Much of the focus of researchers in this field within the past decade has been to find ways of reducing the cost of cement used in sandcrete and soilcrete block production so as to provide low-cost buildings in the suburbs and villages of South Eastern Nigeria. Agricultural by-products regarded as wastes in technologically underdeveloped societies are increasingly being investigated as partial replacement of Ordinary Portland Cement (OPC). Blended cements are already used in many parts of the world since it has been established that supplementary cementitious materials prove to be effective to meet most of the requirements of durable cement composites (Bakar, Putrajaya, and Abdulaziz, 2010). Incorporating agricultural by-product pozzolans such as rice husk ash (RHA) calcined at high temperatures has been studied with positive results in the manufacture and application of blended cements (Malhotra and Mehta, 2004). Agbede and Obam (2008) have investigated the strength properties of OPC-RHA blended sandcrete blocks. They replaced various percentages of OPC with RHA and found that up to 17.5% of OPC can be replaced with RHA to produce good quality sandcrete blocks. Ganesan, Rajagopal, and Thangavel (2008) assessed the optimal level of replacement of OPC with RHA for strength and permeability properties of blended cement concrete.Nair, Jagadish, and Fraaij (2006) found that RHA could be a suitable alternative to OPC for rural housing. Cisse and Laquerbe (2000) reported that sandcrete blocks obtained with unground Senegalese RHA as partial replacement of OPC had greater mechanical resistance than 100% OPC sandcrete blocks. Their study also revealed that the use of unground RHA enabled production of lightweight sandcrete block with insulating properties at a reduced cost. Elinwa and Awari (2001) found that groundnut husk ash could be suitably used as partial replacement of OPC in concrete making. Oyekan and Kamiyo (2011) reported that sandcrete blocks made with RHA-blended cement had lower heat storage capacity and lower thermal mass than 100% OPC sandcrete blocks. They explained that the increased thermal effusivity of the sandcrete block with RHA content is an advantage over 100% OPC sandcrete block as it enhances human thermal comfort. Several other researchers have also investigated the combination of OPC with different percentages of a pozzolan in making binary blended cement composites (Adewuyi and Ola, 2005; De Sensale, 2006; Saraswathy and Song, 2007). Wada et al. (2000) demonstrated that RHA mortar and concrete exhibited higher compressive strength than the control mortar and concrete. Mehta and Pirtz (2000) investigated the use of rice husk ash to reduce temperature in high strength mass concrete and concluded that RHA is very effective in reducing the temperature of mass concrete compared to OPC concrete. Malhotra and Mehta (2004) reported that ground RHA with finer particle size than OPC improves concrete properties as higher substitution amounts result in lower water absorption values and the addition of RHA causes an increment in the compressive strength. Sakr (2006) investigated the effects of silica fume and rice husk ash on the properties of heavy weight concrete and found that these pozzolans gave higher concrete strengths than OPC concrete at curing ages of 28 days and above. Cordeiro, Filho, and Fairbairn (2009) investigated Brazilian RHA and rice straw ash (RSA) and demonstrated that grinding increased the pozzolanicity of RHA and that high strength of RHA, RSA concrete makes production of blocks with good bearing strength in a rural setting possible. Their study showed that combination of RHA or RSA with lime produces a weak cementitious material which could however be used to stabilize laterite and improve the bearing strength of the material. Rukzon, Chindaprasirt, and Mahachai (2009) studied the effect of grinding on the chemical and physical properties of rice husk ash and the effects of RHA fineness on properties of mortar and found that pozzolans with finer particles had greater pozzolanic reaction. Cordeiro, Filho, and Fairbairn (2009) further investigated the influence of different grinding times on the particle size distribution and pozzolanic activity of RHA obtained by uncontrolled combustion in order to improve the performance of the RHA. The study revealed the possibility of using ultrafine residual RHA containing high-carbon content in high-performance concrete. Habeeb and Fayyadh (2009) also investigated the influence of RHA average particle size on the properties of concrete and found that at early ages the strength was comparable, while at the age of 28 days finer RHA exhibited higher strength than the sample with coarser RHA. Pioneer researches have also been carried out on the possibility of ternary blended systems whereby OPC is blended with two different pozzolans. The ternary blended system has two additional economic and environmental advantages. First, it makes it possible for two pozzolans to be combined with OPC even if neither of them is available in very large quantity. Second, it enables a further reduction of the quantity of OPC in blended cements. Elinwa, Ejeh, and Akpabio (2005) investigated the use of sawdust ash in combination with metakaolin as a ternary blend with 3% added to act as an admixture in concrete. Tyagher, Utsev, and Adagba (2011) found that sawdust ash-lime mixture as partial replacement for OPC is suitable for the production of sandcrete hollow blocks. They reported that 10% replacement of OPC with SDA-lime gave the maximum strength at water-cement ratio of 0.55 for 1:8 mix ratio. Frı´as et al. (2005) studied the influence of calcining temperature as well as clay content in the pozzolanic activity of sugar cane straw-clay ashes-lime systems. All calcined samples showed very high pozzolanic activity and the fixation rate of lime varied with calcining temperature and clay content. Rukzon and Chindaprasirt (2006) investigated the strength development of mortars made with ternary blends of OPC, ground RHA, and classified fly ash (FA). The results showed that the strength at the age of 28 and 90 days of the binary blended cement mortar containing 10 and 20% RHA were slightly higher than those of the control, but less than those of FA. Ternary blended cement mixes with 70% OPC and 30% of combined FA and RHA produced strengths similar to that of the control. The researchers concluded that 30% of OPC could be replaced with the combined FA and RHA pozzolans without significantly lowering the strength of the mixes. Fadzil et al. (2008) have also studied the properties of ternary blended cementitious (TBC) systems containing OPC, ground Malaysian RHA, and fly ash (FA). They found that compressive strength of concrete containing TBC gave low strength at early ages, even lower than that of OPC, but higher than binary blended cementitious (BBC) concrete containing FA. Their results suggested the possibility of using TBC systems in the concrete construction industry and that TBC systems could be particularly useful in reducing the volume of OPC used. Much of the previous works by researchers on ternary blended cements were based on the ternary blending of OPC with an industrial by-product pozzolan such as FA or silica fume (SF) and an agricultural by-product pozzolan, notably RHA. Tons of agricultural and plant wastes such as cassava waste (the peelings from cassava tubers) and plantain leaf are generated in the various local communities in South Eastern Nigeria due to intensified food production and local economic ventures. Very little literature is available on the possibility of binary combination of these Nigerian agricultural by-products with OPC in developing blended cements and no literature exists on the possibility of ternary blending of two of them with OPC. This work is part of a pioneer investigation of the suitability of using two Nigerian agricultural by-products in ternary blend with OPC for sandcrete and soilcrete block making. The compressive strength of binary and ternary blended cement sandcrete and soilcrete blocks containing cassava waste ash and plantain leaf ash was specifically investigated. It is hoped that the successful utilization of cassava waste ash and plantain leaf ash in binary and ternary combination with OPC for making sandcrete and soilcrete blocks would go a long way in reducing the cost of building and minor civil engineering projects that make much use of sandcrete and soilcrete blocks as well as add economic value to these agricultural by-product wastes.

II. METHODOLOGY

Cassava waste (the peelings from cassava tubers) was obtained from Ihiagwa in Imo State and plantain leaf from Ogbunike in AnambraState, all in South Eastern Nigeria. These materials were air-dried and calcined into ashes in a locally fabricated furnace at temperatures generally below 650^{o}C. The cassava waste ash (CWA) and plantain leaf ash (PLA) were sieved and large particles retained on the 600μm sieve were discarded while those passing the sieve were used for this work. No grinding or any special treatment to improve the quality of the ashes and enhance their pozzolanicity was applied. The CWA had a bulk density of 820 Kg/m^3, specific gravity of 1.95, and fineness modulus of 1.88. The PLA had a bulk density of 750 Kg/m^3, specific gravity of 1.80, and fineness modulus of 1.35. Other materials used for the work are Ibeto brand of Ordinary Portland Cement (OPC) with a bulk density of 1650 Kg/m^3 and specific gravity of 3.13; river sand free from debris and organic materials with a bulk density of 1590 Kg/m^3, specific gravity of 2.68, and fineness modulus of 2.82; laterite also free from debris and organic materials with a bulk density of 1450 Kg/m^3, specific gravity of 2.30, and fineness modulus of 3.30; and water free from organic impurities.

A simple form of pozzolanicity test was carried out for each of the ashes. It consists of mixing a given mass of the ash with a given volume of Calcium hydroxide solution [$Ca(OH)_2$] of known concentration and titrating samples of the mixture against H_2SO_4 solution of known concentration at time intervals of 30, 60, 90, and 120 minutes using Methyl Orange as indicator at normal temperature. For each of the ashes the titre value was observed to reduce with time, confirming the ash as a pozzolan that fixed more and more of the calcium hydroxide, thereby reducing the alkalinity of the mixture. A standard mix ratio of 1:6 (blended cement: laterite) was used for both the sandcrete and the soilcrete blocks. Batching was by weight and a constant water/cement ratio of 0.6 was used. Mixing was done manually on a smooth concrete pavement. For binary blending with OPC, each of the ashes was first thoroughly blended with OPC at the required proportion and the homogenous blend was then mixed with the sand in the case of sandcrete blocks and with laterite in the case of soilcrete blocks, also at the required proportions. For ternary blending, the two ashes were first blended in equal proportions and subsequently blended with OPC at the required proportions before mixing with the sand or laterite, also at the required proportions. Water was then added gradually and the entire sandcrete or soilcrete heap was mixed thoroughly to ensure homogeneity.

One hundred and thirty-five (135) solid sandcrete blocks and one hundred and thirty-five (135) solid soilcrete blocks of 450mm x 225mm x 125mm were produced with OPC-CWA binary blended cement, one hundred and thirty-five (135) with OPC-PLA binary blended cement, and one hundred and thirty-five (135) with OPC-CWA-PLA ternary blended cement, each at percentage OPC replacement with pozzolan of 5%, 10%, 15%, 20%, and 25%. Twenty seven (27) sandcrete blocks and twenty seven (27) soilcrete blocks were also produced with 100% OPC or 0% replacement with pozzolan to serve as control. This gives a total of 432 sandcrete blocks and 432 soilcrete blocks. All the blocks were cured by water sprinkling twice a day in a shed. Three sandcrete blocks and three soilcrete blocks for each OPC-pozzolan mix and the control were tested for saturated surface dry bulk density and crushed to obtain their compressive strengths at 3, 7, 14, 21, 28, 50, 90, 120, and 150 days of curing.

III. RESULTS AND DISCUSSION

The pozzolanicity test confirmed both the CWA and the PLA as pozzolans since they fixed some quantities of lime over time. The particle size analysis showed that both ashes were much coarser than OPC, the reason being that they were not ground to finer particles. This implies that the compressive strength values obtained using them could still be improved upon if the ashes are ground to finer particles. The compressive strengths of the OPC-CWA and OPC-PLA binary blended cement sandcrete and soilcrete blocks as well as the OPC-CWA-PLA ternary blended cement sandcrete and soilcrete blocks are shown in tables 1, 2, and 3 for 3-14 days, 21-50 days, and 90-150 days of curing respectively.

Table 1. Compressive strength of blended OPC-CWA-PLA cement sandcrete and soilcreteblocks at 3-14 days of uring

OPC Plus	Compressive Strength of sandcrete blocks (N/mm^2)						Compressive Strength of soilcrete blocks (N/mm^2)					
	0% Poz.	5% Poz.	10% Poz.	15% Poz.	20% Poz.	25% Poz.	0% Poz.	5% Poz.	10% Poz.	15% Poz.	20% Poz.	25% Poz.
	Strength at 3 days						Strength at 3 days					
CWA	0.90	0.65	0.60	0.55	0.45	0.40	0.80	0.60	0.55	0.50	0.40	0.35
PLA	0.90	0.65	0.55	0.50	0.45	0.40	0.80	0.55	0.50	0.45	0.35	0.30
CWA& LA	0.90	0.65	0.55	0.50	0.45	0.40	0.80	0.60	0.55	0.45	0.35	0.30
	Strength at 7 days						Strength at 7 days					
CWA	1.50	1.30	1.25	1.15	1.05	0.90	1.25	1.15	1.00	0.90	0.80	0.70
PLA	1.50	1.25	1.20	1.15	1.00	0.90	1.20	1.05	0.95	0.85	0.75	0.65
CWA& LA	1.50	1.25	1.20	1.15	1.00	0.90	1.20	1.10	0.95	0.85	0.75	0.65
	Strength at 14 days						Strength at 14 days					
CWA	2.70	2.30	2.25	2.20	2.00	1.80	2.30	2.00	1.85	1.80	1.70	1.60
PLA	2.70	2.30	2.20	2.10	1.95	1.80	2.30	1.95	1.80	1.75	1.65	1.55
CWA& LA	2.70	2.30	2.20	2.15	1.95	1.80	2.30	1.95	1.85	1.75	1.65	1.55

Table 2. Compressive strength of blended OPC-CWA-PLA cement sandcrete and soilcreteblocks at 21-50 days of curing

OPC Plus	Compressive Strength of sandcrete blocks (N/mm^2)						Compressive Strength of soilcrete blocks (N/mm^2)					
	0% Poz.	5% Poz.	10% Poz.	15% Poz.	20% Poz.	25% Poz.	0% Poz.	5% Poz.	10% Poz.	15% Poz.	20% Poz.	25% Poz.
	Strength at 21 days						Strength at 21 days					
CWA	3.50	3.20	3.10	3.00	2.90	2.75	3.10	2.75	2.60	2.50	2.40	2.30
PLA	3.50	3.15	3.05	2.90	2.85	2.70	3.10	2.70	2.55	2.45	2.35	2.25
CWA& LA	3.50	3.15	3.05	2.90	2.90	2.75	3.10	2.70	2.55	2.45	2.35	2.25
	Strength at 28 days						Strength at 28 days					
CWA	4.40	4.10	4.00	3.90	3.80	3.65	3.90	3.55	3.40	3.35	3.25	3.15
PLA	4.40	4.05	3.90	3.80	3.75	3.55	3.90	3.50	3.40	3.25	3.20	3.20
CWA& LA	4.40	4.05	3.95	3.85	3.80	3.60	3.90	3.50	3.40	3.30	3.20	3.20
	Strength at 50 days						Strength at 50 days					
CWA	4.70	4.60	4.50	4.40	4.45	4.30	4.30	4.40	4.25	4.15	4.05	3.95
PLA	4.70	4.60	4.45	4.40	4.35	4.20	4.30	4.35	4.30	4.15	4.00	3.95
CWA& LA	4.70	4.60	4.45	4.40	4.35	4.25	4.30	4.35	4.30	4.15	4.00	3.95

Table 3. Compressive strength of blended OPC-CWA-PLA cement sandcrete and soilcreteblocks at 90-150 days of curing

OPC Plus	Compressive Strength of sandcrete blocks (N/mm^2)						Compressive Strength of soilcrete blocks (N/mm^2)					
	0% Poz.	5% Poz.	10% Poz.	15% Poz.	20% Poz.	25% Poz.	0% Poz.	5% Poz.	10% Poz.	15% Poz.	20% Poz.	25% Poz.
	Strength at 90 days						Strength at 90 days					
CWA	4.90	5.00	4.90	4.80	4.75	4.50	4.50	4.70	4.65	4.55	4.35	4.25
PLA	4.90	5.00	4.95	4.80	4.70	4.40	4.50	4.70	4.60	4.55	4.30	4.20
CWA& LA	4.90	5.00	4.90	4.80	4.75	4.45	4.50	4.70	4.60	4.55	4.30	4.20
	Strength at 120 days						Strength at 120 days					
CWA	5.10	5.65	5.55	5.45	5.30	5.20	4.60	5.00	4.90	4.80	4.70	4.60
PLA	5.10	5.60	5.55	5.40	5.20	5.10	4.60	5.00	4.90	4.75	4.60	4.50
CWA& LA	5.10	5.60	5.55	5.40	5.20	5.10	4.60	5.00	4.90	4.80	4.75	4.55
	Strength at 150 days						Strength at 150 days					
CWA	5.20	5.95	5.80	5.70	5.65	5.30	4.65	5.10	5.00	4.90	4.80	4.70
PLA	5.20	5.80	5.70	5.60	5.55	5.20	4.65	5.05	4.90	4.80	4.70	4.60
CWA& LA	5.20	5.90	5.80	5.65	5.60	5.25	4.65	5.10	4.95	4.85	4.75	4.65

The results in tables 1 to 3 show that the values of soilcrete block strength are consistently less than the corresponding values of sandcrete block strength for all percentages of OPC replacement with pozzolans and at all curing ages. This confirms the superiority of sand over laterite as fine aggregate material in making cement composites. Nonetheless, a close examination of the results shows that the values of the soilcrete block strengths are not much different from those of sandcrete block strengths. For example, the 50-day strengths are 4.70N/mm^2 for sandcrete block and 4.30N/mm^2 for soilcrete block at 100% OPC and 4.45N/mm^2 for sandcrete block and 4.30N/mm^2 for soilcrete block at 10% replacement of OPC with CWA-PLA in ternary blending. This also confirms that laterite could be used as sole fine aggregate in making cement composites for low-cost houses in communities where sharp sand is difficult to obtain at affordable prices.

The strength values for OPC-CWA and OPC-PLA binary blended cement sandcrete and soilcrete blocks as well as those of OPC-CWA-PLA ternary blended cement sandcrete and soilcrete blocks were all less than the equivalent control values at 3-50 days of hydration for all percentage replacements of OPC with pozzolans. The strength values of the binary and ternary blended cement sandcrete and soilcrete blocks were the same with the equivalent control values at about 90 days of hydration and greater than the control values at curing ages beyond 90 days. The 150-day strength values for OPC-CWA-PLA ternary blended cement sandcrete and soilcrete blocks were respectively 5.90N/mm^{2}and 5.10N/mm^2 for 5% replacement, 5.80N/mm^{2}and 4.95N/mm^2 for 10% replacement, 5.65N/mm^{2}and 4.85N/mm^{2}for 15% replacement, 5.60N/mm^{2}and 4.75N/mm^{2}for 20% replacement, and 5.25N/mm^{2}and 4.65N/mm^2 for 25% replacement; while the control values were 5.20N/mm^2 and 4.65N/mm^2. The lower strength values of blended cement sandcrete and soilcrete blocks at earlier days of hydration shows that pozzolanic reaction was not yet much at those earlier periods; the pozzolanic reaction became higher at later ages and this accounts for the much increase in strength of blended cement sandcrete and soilcrete blocks compared to the control specimens.

It can also be seen from tables 1-3 that the strength values of OPC-CWA binary blended cement sandcrete and soilcrete blocks were consistently marginally greater than those of OPC-PLA binary blended cement sandcrete and soilcrete blocks for all percentage replacements of OPC with pozzolans and at all curing ages. The strength of the OPC-CWA-PLA ternary blended cement sandcrete and soilcrete blocks was consistently in-between the values of the OPC-CWA and OPC-PLA binary blended cement sandcrete and soilcrete blocks. This suggests that more CWA than PLA should be utilized if the two pozzolans were to be used in unequal proportions to optimize the strength of the OPC-CWA-PLA ternary blended cement sandcrete and soilcrete blocks. Moreover, the closeness in strength values of OPC-CWA and OPC-PLA binary blended cement sandcrete and soilcrete blocks and the fact that the strength of the OPC-CWA-PLA ternary blended cement sandcrete and soilcrete blocks was in-between these values suggests that the two agricultural by-product pozzolans could be combined in any available proportions individually in binary blending or together in ternary blending with OPC in making blended cement sandcrete and soilcrete blocks.

IV. CONCLUSIONS

The strength values of soilcrete blocks were found to be less than those of sandcrete blocks for all percentages of OPC replacement with pozzolans and at all curing ages. Therefore, sand should be used in preference to laterite for cement blocks making. However, since the soilcrete block strengths were not much less than the equivalent sandcrete block strengths, good quality laterite is still suitable for block making in the various communities where sand is scarce and unaffordable to the rural populace. OPC-CWA and OPC-PLA binary blended cement sandcrete and soilcrete blocks as well as OPC-CWA-PLA ternary blended cement sandcrete and soilcrete blocks have compressive strength values less than those of 100% OPC sandcrete and soilcrete blocks for 5-25% replacement of OPC with pozzolans at 3-50 days of hydration. The blended cement sandcrete and soilcrete block strength values become equal to the control values at about 90 days of curing and greater than the control values beyond 90 days of hydration. Thus, OPC-CWA and OPC-PLA binary blended cements as well as OPC-CWA-PLA ternary blended cement could be used in producing sandcrete and soilcrete blocks with sufficient strength for use in building and minor civil engineering works where the need for high early strength is not a critical factor.

The strength of OPC-CWA binary blended cement sandcrete and soilcrete blocks is consistently greater than that of OPC-PLA binary blended cement specimens for all percentage replacements of OPC with pozzolans and at all curing ages. The strength values of OPC-CWA-PLA ternary blended cement sandcrete and soilcrete blocks were consistently in-between the values of OPC-CWA and OPC-PLA binary blended cement sandcrete and soilcrete blocks. This suggests that more CWA should be used than PLA if the two pozzolans were to be used in unequal proportions to optimize the strength of the OPC-CWA-PLA ternary blended cement sandcrete and soilcrete blocks. Moreover, the closeness in strength values of OPC-CWA and OPC-PLA binary blended cement sandcrete and soilcrete blocks and the fact that the strength of the OPC-CWA-PLA ternary blended cement sandcrete and soilcrete blocks was in-between these values suggests that the two agricultural by-product pozzolans could be combined in any available proportions individually in binary blending or together in ternary blending with OPC in making blended cement sandcrete and soilcrete blocks for use in various Nigerian communities.

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