Study of Influence of Recycled Waste Plastic Bottles (PET) in Concrete Masonry Units

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Abstract- In Nigeria, plastic-based products are getting more demand in many industries for packaging. Also, the disposal of plastics is also getting serious and there are still no solutions yet to cope with this matter. The objective of this research is to find an alternative way to cope with this environmental problem. Polyethylene Terephthalates (PET) were used for the production of sandcrete blocks of size 225 x 225 x450 mm. The PET bottles were filled with sand and arranged in the mould vertically and horizontally. This gave rise to two sample types: Vertical Bottle with Sand (VBS), and Horizontal Bottles with Sand (HBS). Eight PET bottles were placed in each block mould to create void in the masonry units. The mix ratio used in this research was 1:6 with water-cement ratio of 0.6. The PET sandcrete blocks were tested for compressive and flexural strength after 7 and 28 days. Thermal conductivity test was also carried out on the PET blocks. Plastic PET blocks gave higher compressive and flexural strength at 7 and 28 days when compared with sandcrete blocks without the PET bottles. It was, however, observed that HBS sandcrete block gave the highest strength and the lowest thermal conductivity. The use of PET bottles in sandcrete blocks will improve the strength and thermal performance of blocks while saving the environment from pollution.

Indexed Terms- Sandcrete, PET bottles, Compressive strength, Flexural strength, thermal conductivity.

I. INTRODUCTION

One of the biggest concerns of the century is the management of solid waste globally. The major source of environmental damage is poor solid waste management. The amount of plastic garbage and the fact that it is not biodegradable are two factors of environmental deterioration (Tokpomehoun, *et al*, 2022). Plastic bottle reuse typically requires certain procedures, which restricts its potential (Rathinam, *et al*, 2017). For this reason, plastic bottles are found everywhere in our cities, especially in areas where storm water has accumulated them. Recycling these waste plastic bottles is a key component in contributing to environmental protection and reducing the trend of global warming (Tokpomehoun, *et al*, 2022).

The Society of Plastic Industry (SPI) established a classification system in 1988 to allow consumers and recyclers to identify different types of plastic. Manufacturers place an SPI code, or number, on each plastic product, usually moulded into the bottom. Table 1 provides a basic outline of the different plastic types, their code number, general properties and uses.

Table 1: Types of plastic

Plastic Type	Full Names	General Properties	Common Household Uses
	Polyethylene Terephthalate	i. Good gas and moisture barrier properties ii. High heat resistant iii. Clear iv. Tough	i. Mineral water, Fizzy drinks ii. Fibre for clothing and carpets iii. Shampoo and

		v. Microwave transparency vi. Solvent resistant	mouthwash bottle
2 HDPE 	High-Density Polyethylene	i. Excellent moisture barrier properties ii. Excellent chemical resistance iii. Hard to semi-flexible and strong iv. Soft waxy surface v. Permeable to gas vi. HDPE films crinkles to the touch vii. Pigmented bottles stress resistant	i. Detergent, bleach and fabric conditioner bottles ii. wheeled refuse bin, compost container iii. Toys, buckets, crates, plant pots
3 V 	Polyvinyl Chloride	i. Excellent transparency ii. Hard, rigid (flexible when plasticized) iii. Good chemical resistance iv. Long term stability v. Good weathering ability vi. Stable electrical properties vii. Low gas permeability	i. credit cards ii. Pipes and fittings, wires and cables sheathing iii. Synthetic leather product
4 LDPE 	Low-Density Polyethylene	i. Tough and flexible ii. Waxy surface iii. Soft- scratches easily iv. Good transparency v. Low melting point	i. Films , Fertilizer bags ii. Flexible bottles iii. Irrigation pipes iv. some bottle tops

		vii. Stable electrical properties viii. Good moisture barrier properties	
5 PP 	Polypropylene	i. Excellent chemical resistant ii. High melting point iii. Hard but flexible iv. Waxy surface v. Translucent vi. Strong	i. Most bottle tops ii. Syrup bottles iii. Yoghurt and some margarine container
6 PS 	Polystyrene	i. Clear to opaque ii. Glassy surface iii. Rigid or foamed iv. Hard v. Brittle vi. High clarity	i. Yoghurt container ii. Video cases iii. Coat hangers iv. Fast food trays
		vii. Affected by fats and solvent	
7 OTHER 	Polycarbonate and Polylactide	There are other polymers that have wide range of uses, Particularly in engineering sectors. They are identified with the number 7 and OTHER (or a triangle with numbers from 7 to 19)	i. Nylon (PA) ii. Acrylonitrile butadiene styrene (ABS) iii. Polycarbonate (PC)

Source: Society of Plastic Industry (SPI) 1988

Plastic garbage has recently been recycled for a variety of uses in several places across the world. Numerous studies have examined the usage of recycled plastic bottles in the construction sector (Afolayan, *et al*, 2018; Oppong and Ampofo, 2017; Mokhtar et al, 2016; Muyen *et al* , 2016; Pandey et al, 2017; Patil *et al*, 2018; Premalatha, *et al*, 2016; Shah and Pate, 2016). For instance, they have been employed in the construction of greenhouses and the strengthening of roads. They have also been applied to other fields including agriculture and art decoration (Tokpomehoun, *et al*, 2022). A recent development in the construction sector, plastic bottle sandcrete masonry, can help to achieve social fairness by bridging the housing gap between the wealthy and the poor in Nigeria (Tomori and Adedeji, 2019). For construction to be stronger and more affordable, the construction industry needs to develop cost-effective materials. Many researchers studied the possibilities of utilizing plastic waste as recycled material in different aspect such as concrete construction, bitumen modification, and furniture (Rafiq *et al*, 2022). Example of this material is PET, a kind of polyethylene frequently used for water and fizzy beverage bottles. PET bottles are discarded everywhere and this is a problem the environment is facing because plastic waste requires methods for recycling or reusing and is difficult to biodegrade (Tomori and Adedeji, 2019).

The country is struggling with the challenges of having too many landfills and the effects of discarding plastic water bottles due to the rise in the use of plastic bottles (Hoornweg and Bhada-Tata, 2012). One of the non-biodegradable wastes, PET bottles makes up the majority of landfills in Nigeria. Some of these bottles find their ways to the drains, clogging the drains. The technology of using plastic bottles in construction is now adopted in a number of nations, including Nigeria, South Africa, Norway, the Philippines, and India, according to Muyen *et al*. (2016). These have been used in more than 50 construction projects in Honduras, Columbia, and Bolivia. Figures 1 and 2 show how and where plastic bottles are used in construction. Plastic bottles can be used in place of traditional bricks in walls and pillars when filled with soil or sand to act as bricks. According to Muyen *et al* (2016), homes constructed with PET bricks are "more durable, earthquake resistant, naturally insulated, affordable, and environmentally friendly." They have also so far been demonstrated to be earthquake resistant (www.eco-tecnologia.com, 2018).

A lot of researches have been carried out on how to use plastic bottles in construction either as a whole or shredded. This research focused on using PET bottles of 600 mls as whole out of all classification of the plastic and capacity, this is because they are the most common in landfill. These PET bottles are filled with sand (well compacted), gave them two possible arrangement in the block mould or on –site arrangement and check for not only compressive and flexural strength but thermal conductivity of the PET blocks.

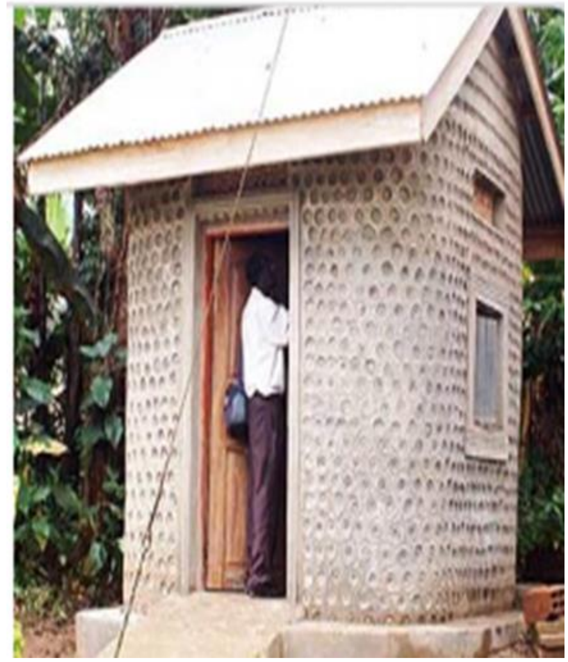

Figure 1: Plastic bottle farm house in Uganda
Source: (Bwire and Nakiwala, 2013

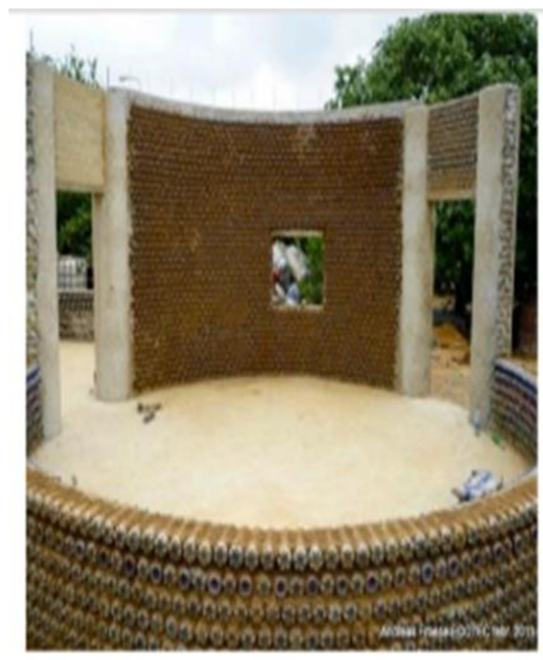

Figure 2: Plastic bottle construction in Yelwa, Nigeria.
Source: Hattam (2011)

II. METHODOLOGY

The method of study designed for this research included tests for 70 sandcrete blocks. In each block eight plastic bottles (600 ml) were positioned vertically and horizontally in each block. Main purpose is to control the concrete masonry to meet the ASTM C140 (Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units) requirements. The compressive strength, flexural and thermal conductivity test were conducted.

Preparation of Samples

Collection of Samples: The soil sample (sharp sand) used for this project was collected from Assembly hall drainage, South campus, The Polytechnic Ibadan, Oyo State, Nigeria. Elephant limestone cement of grade 32.5R in agreement with specifications ASTM C150 was used and water used for casting was obtained from the Water Laboratory, The Polytechnic Ibadan. The PET bottles were also sourced within the campus of The Polytechnic Ibadan, Ibadan, Nigeria.

Preparation of Formwork: A timber formwork was used in the preparation of 225 x 225 x 450 mm solid masonry units for compressive strength, flexural and thermal conductivity tests. The formwork was made according to the size of the concrete masonry units needed and properly nailed to withstand the tapping process during casting. The PET bottles were carefully arranged following specifications most especially the vertical orientation, this was done to ensure that the PET bottles do not shift in position when casting and tamping of sandcrete in the mould. The formwork was oiled before the sandcrete was poured for easy removal when demoulding.

Preparation of Plastic Bottles: Waste PET bottles of 600 mls were packed. In each concrete block mould, eight bottles were used. Twenty-eight moulds were prepared with eight bottles sand filled in each. The bottles were divided in three layers (200 mls each); each layer was filled with sand and given 25 blows according to IS: 14858-2000, using tamping rod, 16 ± 0.5 mm dia and 600 ± 2 mm long according to IS:10086-1982, before placing them in block mould.. A total number of 224 PET bottles were used for this research. Figure 3 shows the empty waste PET bottles and those filled with sand.

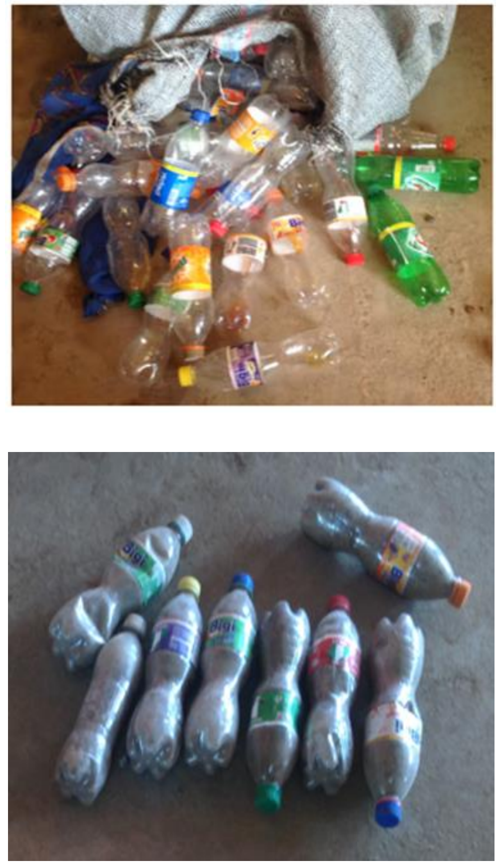

Figure 3: Empty waste PET bottles and those filled with sand.

Preparation of Sandcrete Masonry Unit with Plastic Bottles: A total number of 42 sandcrete blocks of size 225 mm wide by 225 mm high by 450 mm long were cast. A total number 28 blocks were produced with eight plastic bottles (600 ml) each in it; these bottles created voids in the masonry unit. The bottles were arranged in the mould as follows:

i. Vertical arrangement of PET bottles filled with sand (VBS)
ii. Horizontal arrangement of PET bottles filled with sand (HBS)

Control samples (Concrete masonry unit without PET bottles) were also prepared. A total number of 14 samples were cast for control (three samples each for compressive and flexural strength tests after 7 and 28 days, and two for thermal conductivity test). The vertical and horizontal arrangements are shown in Figure 4.

Figure 4: Vertical Arrangement and Horizontal Arrangements

Casting Procedure:
The ingredients of sandcrete block (cement and sand) were weighed out in accordance to the mix proportion 1:6 of each batch of sandcrete block. The sample was mixed manually until a uniform mix was achieved. The moulds were oiled and placed on a level, rigid, horizontal surface, free from vibration. The PET bottles were carefully arranged according to their orientations.

After mixing, 75 mm thick sandcrete was placed in the mould and was evenly distributed with a hand trowel. This sandcrete serves as bed to receive the PET bottles. The PET bottles were carefully arranged according to their orientations. The mould was then filled up using sandcrete to 150 mm height round the bottles. Then rodding (compacting) was done at each layer by applying 35 blows on each layer according to IS: 14858-2000 (Method of Test for Strength of Concrete) using tamping rod. More sandcrete was added up to 300 mm height of the mould, and then the surface was properly leveled. The sandcrete blocks were then left to harden for the next 24 hours before demoulding. Figure 5 shows the samples after casting.

Figure 5: Samples after casting

Curing of Concrete Masonry Unit:
After 24 hours of casting, the formworks were loosened to remove the masonry units and curing started immediately. To obtain a good quality concrete, demoulding must be followed by curing in a suitable environment.

It is important that the concrete should not be permitted to freeze or dry out, because either of these occurrences would affect the strength development of the concrete. The concrete specimens if kept in a moist environment will gain strength in the first 28 days (Neelakantan *et al.*, 2014).

Since accurate curing is vital in order to give accurate result, the concrete masonry units cast for this project were cured immediately after demoulding by wetting for 7 and 28 days in preparation for the strength tests.

Testing Methods

Compressive Strength Assessment
The compressive test was conducted in accordance with ASTM C39, at the soil laboratory of the Civil Engineering Department, The Polytechnic, Ibadan. The sandcrete masonry was subjected to test after curing in set of three. Three sandcrete masonry units having vertical arrangement of PET bottles filled with sand were subjected to compressive strength test. The same process was repeated for horizontal orientation. A total number of 6 sandcrete masonry units and three

full sandcrete masonry units (control) were checked for their compressive strength after 7 days.

This process was repeated at 28 days for compressive strength test. A total number of 18 sandcrete masonry units were subjected to compressive strength test. Figure 6 shows the compressive strength test process.

Figure 6: Compressive strength test

Flexural Strength Assessment (Centre-Point Loading)
The flexural strength test was conducted in accordance with ASTM C293 in the soil laboratory of the Agricultural and Environmental Engineering Department, University of Ibadan. Three sandcrete masonry units having vertical arrangement of PET bottles filled with sand were subjected to flexural strength test after curing. The same process was repeated for horizontal orientation. Three full sandcrete masonry units (control) were taken out of the curing tank and checked for flexural strength test after 7 days. This process was repeated at 28 days for flexural strength test. For this research, a total number of 18 concrete masonry units were subjected to flexural strength test. Figure 7 shows the flexural strength test process.

Figure 7: Flexural strength test

Thermal Conductivity Test
For this research, a transient method (wire sensor method) in accordance with ASTM D7896 - 19 was used to determine the thermal conductivity of sandcrete block; this test method involved drilling through the sandcrete block (10cm). This was done to receive the sensor. The sensor was then connected to a thermocouple. Sandcrete block was subjected to fire generated from acetylene gas having a constant temperature of 1000ºC. As the sandcrete block conduct heat, the sensor receives the heat and the corresponding temperature was read from

thermocouple. Sandcrete block was subjected to this constant heat of 1000ºC for 2 hours on each specimen types and temperature in (° C) was taken at 15 minutes interval. Figure 8 shows the thermal conductivity test procedure.

Figure 8: Thermal Conductivity test

III. RESULTS AND DISCUSSION

Compressive Strength

The results summary presented in figure 6 are the compressive strength test results after 7 and 28 days, respectively.

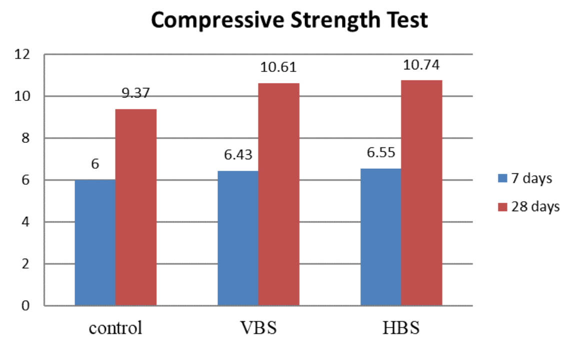

Figure 6: Compressive strenght result after 7 and 28 days

Discussion: Compressive strength of sandcrete blocks (control) at 7 days and 28 days gave 6.00 and 9.37 N/mm^2, respectively, all other strength results having bottles arrangements were compared with these strengths.

From the experimental study, it was observed that sandcrete blocks with horizontal arrangement of bottles filled with sand (HBS) gave the highest compressive strength of 6.55 N/mm^2 after 7 days compared to vertical arrangement of bottles filled with sand (VBS) which gave a compressive strength of 6.43 N/mm^2.

It was also observed that sandcrete blocks with horizontal arrangement of bottles filled with sand (HBS) gave the highest compressive strength of 10.74 N/mm^2 after 28 days compared with vertical arrangement of bottles filled with sand (VBS), which gave a compressive strength of 10.61 N/mm^2.

Flexural Strength Test Results

The results summary presented in figure 7 are the flexural strength test results after 7 and 28 days respectively.

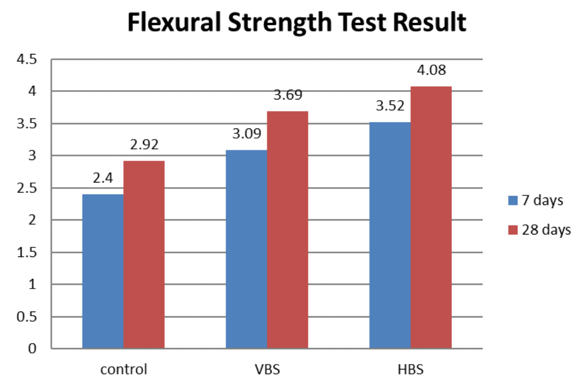

Figure 7: Flexural strenght result after 7 and 28 days

Discussion: Flexural strength of sandcrete blocks (Control) at 7 days and 28 days gave 2.40 N/mm^2 and 2.92 N/mm^2 respectively, all other strength results having bottles arrangements were compared with these strengths.

From the experimental study, it was observed that sandcrete blocks with horizontal arrangement of bottles filled with sand (HBS) gave the highest flexural strength of 3.52 N/mm^2 after 7 days compared with vertical arrangement of bottles filled with sand (VBS), which gave a flexural strength of 3.09 N/mm^2. It was also observed that sandcrete blocks with horizontal arrangement of bottles filled with sand (HBS) gave the highest flexural strength of 4.08 N/mm^2 after 28 days compared with compared with vertical arrangement of bottles filled with sand (VBS), which gave a flexural strength of 3.69 N/mm^2.

Figures 6 and 7 have shown that the compressive and flexural strength of sandcrete blocks with PET bottles gave the highest strength than the conventional solid block strength after 7 and 28 days. This is because PET bottles, a non-biodegradable waste material, possess properties that do not break or fracture under loading plate, hence, it is practically shatter resistant.

From the observations, out of all the sample types, sandcrete block with horizontal bottles filled with sand (HBS) gave the highest compressive and flexural strengths after 7 and 28 days when compared to the conventional sandcrete block (control) and NIS 87:2007 standard. This is due to the fact that plastic bottles laid horizontally created an internal force against the loading plate i.e. it created lateral resistant to the applied load. As the bottles are arranged in layers, the load applied encountered resistant at each layers and lessening the area to be used in compression thereby increasing the strength of HBS sandcrete blocks.

Thermal Conductivity

The results summary presented in figure 8 are the thermal conductivity test results. A constant heat of 1000^{o}C was subjected to the sample blocks for 2 hours. The initial reading on the thermocouple was 27^{o}C and the readings were then taken at every successive 15 minutes for 2 hours

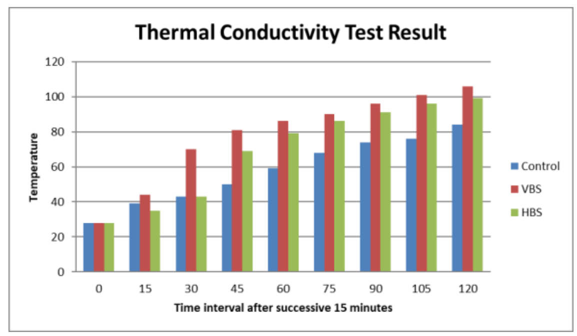

Figure 8: Thermal Conductivity Test Result

Discussion: From the fire resistant test result, it was revealed that it takes the control sample 15 minutes before it could conduct 1^{o}C heat, while it takes HBS, and VBS 12 and 10 minutes respectively before they conducted 1^{o}C heat.

From figure 8, it can be deduced that after 2 hours of subjecting the sample blocks to fire, HBS has the lower heat conductivity of 99^{o}C followed by VBS having 106^{o}C when compared with the control samples having 84^{o}C.

HBS and VBS sandcrete blocks was able to achieve low thermal conductivity test result after 2 hours because HBS and VBS have a medium (sand) in it and this medium is non-combustible and also a fire retardant thereby reducing the heat transfer to the sandcrete block.

Thus, it can be concluded that filled bottle blocks have low thermal conductivity due to the filled medium and it has been discovered that the use of plastic in block gave strength gave higher strength when compared with the conventional blocks.

Comparing this research results with other past researchers work, such as the findings of Mardiha *et.al*. (2017), Muyen *et.al*. (2016) and Shoubi *et.al.* (2013) on bottle blocks. They all revealed that bottle blocks possess more compressive strength, they are found to be stronger and cheaper and are 20 times more load resistant and have great insulating capability than the conventional blocks. Therefore, plastic blocks are qualified to replace standard masonry as a wall material. For these reasons, Muyen *et.al*. (2016), proposed the usage of the bottle bricks in Bangladesh.

CONCLUSIONS AND RECOMMENDATIONS

To compliment the findings on the influence of recycled waste plastic bottles (PET) in concrete masonry units, research has been carried out on the use of plastic bottles in sandcrete blocks. From the research, the following conclusions can be drawn:

1. Plastic PET bottles in concrete masonry unit have higher compressive and flexural strength when compared with control and NIS standard.
2. The samples arranged horizontally i.e. (HBS) gave highest strength when compared to the conventional solid block (control) and NIS 87: 2000 standard.
3. Concrete masonry units whose plastic bottles are filled with sand (HBS and VBS) have lowest heat conductivity and highest fire resistant when compared with solid sandcrete block (control) after 2 hours. After 2 hours of fire resistant, cracks showed on the sandcrete block and the bottle tops melted.

For further research, a lower as well as higher capacity of PET bottles should be used so as to verify if there could be any difference in strength, an increase or decrease in the number of PET bottles in the sandcrete blocks should be considered, likewise, the sample blocks should be subjected to higher heat more than the one used in this research.

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