An Experimental Study on the Mechanical Properties of Partial Nonreactive Silicate based Sugarcane Bagasse ash and Rice husk ash, along with their Polyolefin and Polyester Fiber based Secondary Reinforcement

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Abstract

Supplementary Cementitious Materials, or otherwise known as SCMs are among one of the brightest prospects for substitution of cement in concrete. Addition of these substances enhances efficiency for the mechanical properties in concrete as well as a number of other advantages like reduction in cost and an all-inclusive reduction of carbon emission content. This study provides a detailed overview on some of most abundant SCMs with focus being on use of their less reactive versions that are obtained at higher temperatures, their optimum quantity and proper production process; other than these factors, focus is also shown on providing adequate data on different types of synthetic fibers like polyolefin and polyester fiber for proper understanding, and using their combination as an additive. Consequently, one of the main goals of this study is to create a fiber reinforced composite from discarded less reactive version of sugarcane bagasse ash (SCBA) & rice husk ash (RHA), which are obtained from local jaggery plant and biomass gasifier respectively. Data from technical data sheet is also discussed in the methodology for understanding market and alternatives. A thorough review of literature has also been compiled.

Keywords. supplementary cementitious materials, polyolefin fiber, polyester fiber, rice husk ash, sugarcane bagasse-ash

1. INTRODUCTION

Effects of increasing global warmth have been seen for several decades, the global ocean and land temperature during January 2021 was 0.80 °C above 20th century average, making it the 7th warmest January in 142 years, according to overall global statistics. If that's not enough, considering: 2021 has a 99 percent chance of being among the 10 warmest years on record, with prediction of increased temperature expected in coming years, is a cause for worry.

The worldwide push regarding economic based expansion & infrastructure development puts a considerable strain on the planet's resources, resulting in worrying global warming & carbon emissions. According to Statista data, global cement production needed to fuel the desire for infrastructure development in 2019 was around 4 billion ton, resulting in a terrible 3.5 billion ton of CO^2. Environmental contamination & deterioration, as well as the resource exhaustion of earth during raw material mining, are further concerns related with cement manufacture. Substituting supplemental cementitious materials (SCMs), also known as pozzolanas, for cement clinker is one of the viable ways for reducing these disadvantages. RHA & SCBA are among most promising SCMs.

Properties of these materials can further be enhanced through treatment, the fineness/specific surface-based area and specific gravity of the treated bagasse ash is more than the untreated-bagasse ash. Strength activity index of the treated SCBA is much higher and loss on ignition is also less [3]. Some of the other factors for their proper use include proper silica concentration and dry density, When SCBA was burned at temperatures ranging from 400 C to 800 C, the chemical compositions and colour changed, and the silica concentration rose from 25.32 to 86.98 percent [15]. When moisture content percentage for bagasse ash is zero, a dry density of 1.06g/cm3 was obtained, and an increase in water content up to 24%, resulted in a maximum dry density of 1.15g/cm3, followed by a reduction in dry density [1].

The fineness/specific surface area & specific gravity of BA is more than the RHA. The higher content of silica in RHA helps in formation of more hydration products. Strength activity index of the RHA is much superior than the BA. Hence RHA is a better pozzolan than BA [4]. However, failure to use them as a constituent material can also be due to lack of proper bonding, absence of adequate bonding between SCBA and RHA particles and the cement-based paste, as well as the non-uniform distribution of SCBA and RHA particles in concrete, might result in non-homogeneous samples, leading in a loss in concrete strength. [8].

Synthetic fibers performances are heavily dependent on temperature and rate of dosage, Up to 150 °C, the structural behaviour and fracture energy of PFRC specimens remained unchanged, according to this study. Some qualities degraded between 150 and 200 degrees Celsius, and at 200 degrees Celsius, a large fraction of the fibres was molten. Damage occurred mostly in the concrete matrix of fibre reinforced concrete specimens exposed to 150 °C, Compressive strength, static modulus of elasticity, and ultrasonic pulse velocity all suffer as a result. The absence of any structural capacity was observed in specimens exposed to 200 °C, yet the specimens did not break or show signs of brittle failure [9].

After the beginning of cracking, the energy absorbed by the fibre deformation generated a significant rise in fracture energy in each examined material. This characteristic revealed the ductile behavior of polyolefin fiber-reinforced concrete. At the limit of proportionality, specimens with a smaller fracture surface exhibited higher strength values. Because the concrete matrix governs the limit of proportionality, this value is consistent with the standard size effect idea for plain concrete [10]. According to Pawaskar et al (2020), Compressive strength, flexural strength, & split tensile strength are shown to be highest at 0.50 percent fibre addition and decrease when the proportion of fibre added exceeds 0.50 percent [12].

Agricultural or industrial wastes with latent hydraulic reactivity that can be activated are commonly used as SCM. Among these, SCBA (sugarcane bagasse ash) has been studied extensively as potential SCM. Along with SCBA several additional types of (SCMs) include options like natural pozzolans, silica fume, fly ash, GGBS, MSW ash, rice husk ash, calcined natural SCMs, calcareous fly ash, activated cooper tailings, wood ash, calcined clays, Biomass ash, Bauxite residue, waste glass etc.

2. Rice Husk Ash (RHA)

Rice (Oryza glaberrima) is among world's most important staple-based food crop consumed by more over half of the world's population; annual based production of this grain is about [742,541,804 tonnes]. Rice mills, converts the paddy plant into 78 percent rice, 20percent rice husk, and 2% is wasted during the process. During this process, 20 to 25% of the rice husk will hence be converted to Rice husk ash. RHA are generally less than 45µm & average size of particle is in range 6-10µm. Whereas Rice husks main constituents are 50% cellulose, 25-30% lignin, 15-20% silica and a total moisture of about 10-15percent.Bulk density of rice husk is fairly low & lies in reach of 90-150 kg/m3. Rice husk has a calorific value of roughly 15 MJ/kg, and under regulated burning circumstances, the volatile organic content in the rice husk, such as cellulose and lignin, is eliminated, leaving amorphous silica with a microporous cellular structure as the residual ash. However, several factors must be controlled in order to obtain proper ash, one of which is the temperature and conditions under which rice husk-based ash is scorched, for example, ash obtained from uncontrolled combustion, such as open field burning or industrial furnaces at temperatures greater than 700-800°C, will contain significant amounts of non-reactive silica minerals cristobalite and tridymite.

Reactive/amorphous silica (Si02) content, as well as, other pozzolanic oxides (alumina (A1203) & (Fe203) ferrite, are the primary qualifications of any SCM.As a result, many SCM standards concentrate upon establishing a minimum oxide requirement. ASTM C618, for example, needs pozzolanic oxides (Si02 + A1203 + Fe203) to be larger than 70percent, BS EN 197-1 must have a minimum of 25% S102, and IS 3812-1 must have a minimum 35percent Si02 and 70% pozzolanic oxides. As furnace temperature for obtaining RHA from rice husk is increased, the structure goes towards becoming more crystalline in nature, and naturally the surface keeps on decreasing with increase in temperature or hold time of rise husk within favoured equipment. At a temperature of 500-600 structure nature is non-crystalline, 700-800 gives partially crystalline and above 800 results in crystalline structure. Mean diameters for pores in the microscopic structure of RHA is loftiest when they are scorched at temperatures between 600-700°C, therefore e pozzolanic activities of formed ash is highest at this temperature. When we take variations of particle size with grinding time into account, then with increased grinding time particle size reduces and more importantly BET nitrogen adsorption increases with grinding time (Table 1).

Table 1. Average chemical composition data of RHA & Portland limestone cement [19]

S/N	Chemical Components	Portland Limestone Cement %	RHA (%)
1	**Silica Oxide (SiO_2)**	**19.16**	**88.29**
2	**Sodium Oxide (NaO_2)**	**0.40**	**0.10**
3	**Potassium Oxide (K_2O)**	**0.35**	**2.90**
4	**Calcium Oxide (CaO)**	**64.25**	**0.63**
5	**Magnesium Oxide (MgO)**	**2.17**	**0.46**
6	**Aluminium Oxide (Al_2O_3)**	**4.92**	**0.44**
7	**Iron Oxide (Fe_2O_3)**	**0.75**	**0.65**
8	**Sulphur Oxide (SO_2)**	**1.02**	**0.00**
9	**Loss on Ignition (LOI)**	**0.05**	**5.35**

3. Sugarcane Bagasse Ash

Sugarcane (SC) is a term used to describe tall perennial grasses from the Saccharum officinarum and its hybrids that have a fibrous stalk rich in sucrose that accumulates in the stems and are used as a staple material in the ethanol and sugar industries. The sugarcane bagasse is a by-product of the extraction of juices from the sugarcane stalk (SCB). Bagasse is a fibrous lignocellulose waste with a high bioconversion efficiency, making it a cost-effective fuel for cogeneration facilities in industry.

After the energy is generated, the SCBA is the last waste. If all sugarcane in the world is processed to extract juice for the ethanol and sugar sectors, 420 to 630 million metric tonnes bagasse are produced each year. This is caused due to the fact that bagasse has been estimated to make up 20 to 30percent of the sugarcane stalk. Similarly, based on a 5% weight of bagasse, yearly global SCBA production is estimated to be between 21 and 31.5 million metric tonnes.

To create additional hydration products, pozzolanic oxides must interact with portlandite from cement hydration. Natural SCBA from the sugarcane sector, on the other hand, frequently requires processing or activation to become sufficiently reactive.

Delignification or in other words chemical treatment, exposes inner cellulose microfibrils for easy oxidation. Commonly chemical based activator includes alkali & acid with dilute acid, which are an economic efficient option. On other hand chemical addition involves addition of minerals like nano silica & limestone which can increase cement hydration rates, creating more portlandite for pozzolanic based consumption.

Treated SCBA is finer in nature than untreated type with an approximate 40 % reduction in size. Treatment do not increase the SAI (strength activity index) performance of SCBA. However chemical addition can improve SAI for example, nano silica improves SAI performance, microstructure based chemical adsorption, chloride ion migration, mercury intrusion, electrical resistivity of a mix containing SCBA especially at higher rate of substitution like 25 % substitution of SCBA.

600°C is the optimum calcination temperature as strength activity index is maximum at that temperature. Recalcination process will further increase SAI by at least additional 10% and can restrict loss on ignition to an average of 2.1 % loss, this is possible because of reduction in detrimental carbon content.

4. Polyoelifin Fiber (Ecmas EXF 54- Hybrid Synthetic Structural Fiber)

The synthetic-structural fibre was created to increase the durability & mechanical properties of concrete. EXF 54 is a hybrid fibre, meaning it is composed of a non-fibrillated monofilament having a specific mix of Polyolephinic polymers and a fibrillated Polypropylene fibre capable of reducing, if not fully eliminating, plastic shrinkage. It increases concrete flex fatigue, ductility, fatigue resistance, and durability. Unlike metal fibres, these fibres are non-corrosive, non-magnetic, and acid and alkali proof (Table 2).

Table 2. Technical properties of polyolefin fiber [18]

Material	Mix of fibers of a Polyolephin (Polyethylene Co-Polymer) and a fibrillated Polypropylene fiber)
Length	54 mm
Specific Weight	0.91 kg/dm3
Length/Diameter ratio	113
Equivalent diameter	0.48 mm
Chemical Resistance	Total Resistance to acids, bases and salts
Tensile Strength	620 – 758 MPa
Conformity	ASTM C-1116

It reduces floor thickness & eliminates the requirement for electro-welded mesh and metal fibres. It increases concrete's residual tensile strength, and therefore its ultimate strength and resistance to stress induced by dynamic and static overloads, by efficiently controlling temperature/plastic shrinkage fractures.

Fibers should be hurl directly to the mixer at the prefabrication or concrete mixing plant, or to the mixer truck. Fill the conveyor belt with fibres, inert materials, cement, sand, and the first piece of gravel. Fibers should not be introduced at first. Dry mix for at least 5 minutes on high speed before adding water.

In event of fire, polyolefin fibre deteriorates, as do all synthetic fibres once they reach their melting point. When compared to metal fibres, when they reach melting point during a fire, the fibres disintegrate without emitting toxic fumes, transforming the space they previously filled in cement mixes into a system of linked "channels." When water in gaps suddenly boils, these channels act as "escape routes" for the heat and steam produced. This characteristic prevents fibre reinforced concrete from bursting violently, as steel fibre reinforced concrete or unreinforced concrete would. Concrete density of at least 1.5 kg/m3 is required (to be assessed on basis of the application parameters) (Table 3).

Table 3. Properties for different types of polypropylene fibers [14]

Fiber Type	Density (kg/cm3)	Diameter (mm)	Tensile Strength (Mpa)	Modulus of elasticity (GPa)`	Specific Surface (m2/Kg)	Length (mm)
Fibrillated	0.95	0.20-0.30	500-750	5.00-10.00	58	19-40
Microfilament	0.91	0.05-0.20	330-414	3.70-5.50	225	12-20
Monofilament	0.9	0.30-0.35	547-658	3.50-7.50	91	30-50

Polyolefin fibres, often known as PP fibres, offer good mechanical characteristics in general, with their modulus of elasticity being particularly noteworthy. The naturally occurring modulus value is 9 GPa, with some rising as high as 15–20 GPa, which is way greater than 2–3 GPa provided by certain other plastics. Polyolefin fibres have a tensile strength of around 400 MPa. These remarkable properties were attained by the bicomponent manufacturing of two polymers: a high modulus core and a low modulus sheath.

In terms of a fibre form, the optimum macro synthetic fibre-based geometry involves fully using matrix anchoring without breaking the fibres and attaining maximum pullout resistance. The crimped synthetic structural fibres exhibited the best bonding out of all the deformed synthetic structural fibres tested.

5. POYSTER FIBER (RECRON 3S)

They are microfibers with a peculiar "triangular" cross section that are utilized in secondary concrete reinforcement. It works in tandem with structural steel to improve concrete's resistance to shrinkage cracking and improve mechanical qualities such as flexural/split tensile and transverse strengths, as well as abrasion and impact resistance. They operate as a pumping assist in making concrete more homogeneous by inhibiting the growth of cracks, bridging tiny fissures, and providing stability to the concrete. Reduces the absorption of surface water and the permeability of concrete (Table 4).

Table 4. Properties of Recron fiber [16]

S/N	Units	POLYESTER	POLYPROPYLENE	Properties	Remarks
1		Triangular	Triangular	Shape	
2	mm	3/ 4.8/6/12/18/24	3/ 4.8/6/12/18/24	Cut Length	+/- 1mm, Project specific customized lengths can be produced on request
3	Deg C	250-265	160-165	Melting Point	
4		1.34-1.39	0.90-0.91	Specific Gravity	
5	25-40	microns	20-40	Effective Diameter	
6	Gpd	4-6*	4-6*	Tensile Strength	*Estimated tensile strength in Mpa 4-6 *Polyester 480-730, *Polypropylene 320-490
7	%	20-60	60-90	Elongation	Initial Modulus
8	Mpa	>5000	>4000	Young's Modulus	Tests done as per AC
9		Very Good	Very Good	Alkaline Stability	32 standards

Recron 3S Fibers are manufactured from a ISO 9001:2000 facility and are intended for use as secondary reinforcement in concrete at dosage rates ranging from 0.1 to 0.4 percent by volume (0.9 kgs/Cu. M to 3.60 kgs/Cu. M). ASTM (C 1116), Type (111) Fiber Reinforced Concrete requirements are met by the fibres.

These fibres are produced by polymerizing raw ingredients such as Pure-Terephthalic Acid (PTA) & Mono-Ethylene Glycol (MEG) with catalysts, which results in finished polyester yarn via a continuous extrusion process. After that, the finished yarn is automatically cut to the necessary length and wrapped in pouches. Quality assurance on raw materials & production processes done by ISO 9001:2000 standards.

6. FIBER PULL-OUT RESPONSE

Irrespective of type of fiber used, reinforcement is only successful in concrete when tensile strength of fiber is two to three times higher than that of concrete, when modulus of elasticity of fiber is way higher than conventional concrete & fiber-matrix based strength of bonding is of same order magnitude for tensile strength of the matrix. Crack opening is controlled in an ideal circumstance by fibre bridging, which contains a segment of fibre on either side of the crack with sufficient embedded length to prevent slippage (Figure 1).

Conversely, if fibers slip during the opening process, de-bonding may occur, and the fiber may be pulled out. It's possible that friction shear forces will produce matrix fracture if one fiber is mobilized. In order to identify which of the two situations might emerge, the critical length (lc, the length at which the fiber's tensile strength can be utilized without drawing it out of the matrix) of fibres is the deciding factor. Chemical adhesion & frictional bond one on internal part and other at end of crack is the ideal situation.

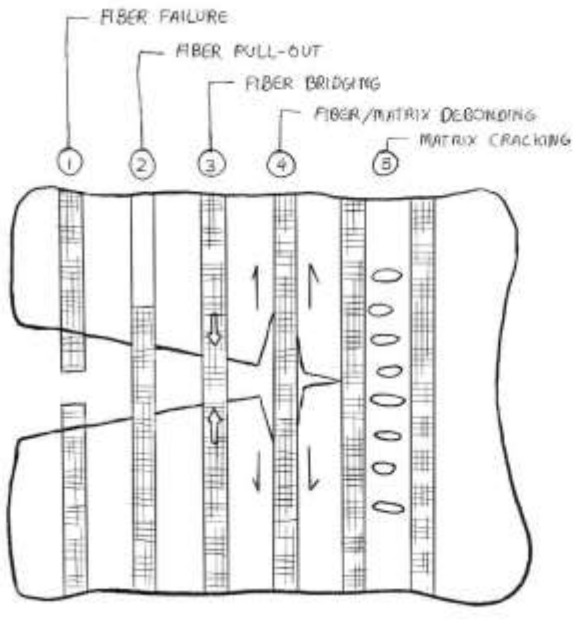

Figure 1. Fiber matrix mechanisms

7. Mix Design

Various parameters of the design are listed in Table 5 and Table 6.

Table 5. Mix Design of Sugarcane Bagasse Ash [20]

Specimen	SCBA (%)	Quantity (kg/m^3)					
		Cement	SCBA	Polyolefin fiber +Polyester fiber (additive)	Water	Coarse Aggregate	Fine Aggregate
M30	0%	426	0	1.5+0.9	192	1186	701
M30+10%SCBA	10%	385.185	42.60	1.5+0.9	192	1186	701
M30+12.5%SCBA	12.5%	373.333	53.25	1.5+0.9	192	1186	701
M30+15%SCBA	15%	361.481	63.90	1.5+0.9	192	1186	701

Table 6. Mix Design of Rice Husk Ash [20]

Specimen	RHA (%)	Quantity (kg/m^3)					
		Cement	RHA	Polyolefin fiber +Polyester fiber (additive)	Water	Coarse Aggregate	Fine Aggregate
M30	0%	426	0	1.5+0.9	192	1186	701
M30+5%RHA	5%	404.691	21.30	1.5+0.9	192	1186	701
M30+7.5%RHA	7.5%	394.074	31.95	1.5+0.9	192	1186	701
M30+10%RHA	10%	385.185	42.60	1.5+0.9	192	1186	701

8. Mixing Guidelines

In the case of triangular polyester fibre (Recron 3S), in the event of machine mixing, the fibres are placed in the mixer along with some water (5-10 liters) and then other components are added, followed by a continuing mixing process until all fibres are disseminated, which takes a few minutes. In case of manual mixing, half of the fibers are mixed and stirred in a bucket full of water, which is then mixed with other ingredients. Similarly, balance type fibers are also added to mix, according to MSDS of the product use of more than 0.25% of weight of cement is not recommended. specific gravity of this material is 1.36& placing, curing along with finishing is similar to conventional methods (Table 7).

Table 7. General specification according to application requirement [16]

Type	Application	General specification
CT 2012	Plaster, Concrete	6mm length, 125 gm packing
CT 2024	Concrete	12mm length, 125 gm packing
CT 2424	Ready mix concrete	12mm length, 450 gm dissolvable packing

Fibers for POLYOLEFIN (ECMAS EXF 54) should be put directly to the mixer at the prefabrication or concrete mixing plant, or to the mixer truck. Fill the conveyor belt with fibres, inert materials, cement, sand, and the first piece of gravel. Fibers should not be introduced at first. Dry mix for at least 5 minutes on high speed before adding water [18].

9. RESULTS & DISCUSSIONS

From obtained compressive strength based-results its evident that the sugarcane bagasse ash-based composite obtains high early strength in comparison to rice husk ash-based composite but the ultimate strength provided by rice husk ash is comparatively higher in value. Initial strength of rice husk ash-based composite is less than exemplary and can cause issues while using it as a constituent material, but these issues are as of now has been identified in less reactive version of rice husk ash which has non-reactive silicates in it, due to higher temperature at which it was obtained (Table 8, Figure 2).

Table 8. Compressive strength test

Specimen + (Polyolefin & Polyester fiber)	Compressive strength in 7 Days (N/mm^2)	Compressive strength in 14 Days (N/mm^2)	Compressive strength in 28 Days (N/mm^2)
M30	21.20	28.42	31.55
M30+5%RHA	12.61	18.45	24.35
M30+7.5%RHA	15.56	22.19	27.54
M30+10%RHA	18.89	26.75	33.00
M30+10%SCBA	16.78	22.20	26.78
M30+12.5%SCBA	18.75	25.34	27.55
M30+15%SCBA	19.86	27.36	29.20

The strength obtained from sugarcane bagasse ash composite is almost identical to that of polyolefin and polyester fiber-based composite. But as the no of days increase, the increment in its value becomes significantly less. Through these observations it can be suggested that a composite with a combination of both less reactive versions of SCBA & RHA could provide higher early strength, as well as a comparatively higher compressive strength if superplasticizer is added.

Figure 2. General crack bridging and failure mechanism

10. CONCLUSION

In this experimental study, a comprehensive review on different supplementary cementitious materials (SCMs), polyolefin fibers & polyester fiber have been discussed. Furthermore, technical data on commercially available polyolefin fiber and polyester fiber is discussed with their potential impact on concrete properties. A separate chapter for mixing guidelines & fiber pull-out response is also added for better understanding on handling of these fibres to gain maximum benefit. Some of the noteworthy results obtained from this study are as follows

- The experimental study shows that adequate strength can be achieved through the use of SCBA & RHA even in presence of non-reactive silicates formation like meta stable cristobalite, which is caused by burning at higher temperature than recommended ideal temperature range of 600-700°C.
- The study shows that SCBA reaches high early strength, but it also states that the RHA shows very low strength in its earlier phases like at 7 days or 14 days.
- According to obtained data possibility of obtaining a better specimen by combination of SCBA and RHA is very high, however according to technical data its better if the total replacement level to cement is restricted to 20% replacement by weight and amount of RHA should be properly regulated as it can reduce workability of mix exponentially, at higher concentrations.
- The main goal of this project was to obtain similar or higher value then traditional concrete, and that was achieved according to design mix and lab environment parameters.
- Concrete failure at peak loads is adequate and crack bridging effects show proper fiber pullout response, suggesting tensile strength test of specimen would give exceptional results.
- This fiber reinforced composite is very cost effective as it goes as far as to replace 15% of cement content with a waste material, which is discarded and can be obtained at very cheap rates making it a good alternative.
- Other than the cost factor, this material can be considered as more eco-friendly than conventional concrete. This statement can be justified by simply stating the fact that the majority of carbon emissions in construction are related to cement, its production, etc.
- These results show that with higher quality variants of SCBA and RHA, better results can be obtained. This conclusion is rooted in the fact that silica content can reach up to 90% if these materials are burned at their ideal temperature. An ideal temperature also helps in obtaining the highest values of the strength activity index (SAI).
- From the compressive strength results, it is evident that the sugarcane bagasse ash-based composite obtains high early strength in comparison to the rice husk ash-based composite, but the ultimate strength provided by rice husk ash is

comparatively higher in value. The initial strength of the rice husk ash-based composite is less than ideal and can cause issues while using it as a constituent material, but these issues are, as of now, only identified in the less reactive version of rice husk ash, which has non-reactive silicates in it due to the higher temperature at which it was obtained.

- The strength obtained from sugarcane bagasse ash composite is almost identical to that of polyolefin and polyester fiber-based composites. But as the number of days increases, the increment in its value becomes significantly less. Through these observations, it can be suggested that a composite with a combination of both less reactive versions of SCBA and RHA could provide a higher early strength as well as a comparatively higher compressive strength.

Other potential research on use of SCMs can include options like natural pozzolans, silica fume, fly ash, GGBS, MSW ash, rice husk ash, calcined natural SCMs, calcareous fly ash, activated cooper tailings, wood ash, calcined clays, Biomass ash, Bauxite residue, waste glass etc. Meanwhile fibres can be polypropylene, polyolefin, steel fiber, polyethylene, nylon fiber etc.

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