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"Investigation of hot asphalt concrete mixes properties and performance by using waste plastic "

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Abstract

*Global attention is paid to construct eco-friendly road in both advanced countries and Developing countries. It's increased due to the increase of the demands and to decrease the harmful impacts of road construction, also to green our basic substructure. This research clarifies the point of eco-friendly environment through replacing dry waste plastic by percent of the aggregates amount in asphalt mixtures. The purpose of this research is to investigate the possibility of using waste plastic as a polymer additive for asphalt concrete mixtures. Therefore, waste plastic were collected and sorted from different dumps of garbage. Then high-density polyethylene (HDPE) wastes were chosen for doing different tests. Replacement was done with 6%, 8%, 10%, 12% and 14% by aggregates weight. Mixtures containing shredded (HDPE) showed improvement with respect to the Marshall stability and flow properties. Laboratory aging procedures have been set up to simulate the ageing process at 90 °C oven for (*24h, 72hr). *Finally it could improve the performance level and the service life of the road. To sum up (HDPE) modified asphalt mixture gives more advantages compared to the traditional one. Having considered that the environmental and economic features, it is found that the modified mixture at 12% is suitable to be used for road pavements, and improve the mechanical properties and performance of asphalt mixture Compared with traditional mixture. The HDPE modified mixtures had high resistance of water susceptibility, where the indirect tensile strength test (ITS) results values for the modified mixtures had higher value than the traditional mixtures. It is attributed to the HDPE prime-coated, which would be critical for improving moisture susceptibility. Because of lesser density of plastic aggregate, asphalt samples made of replaced plastic aggregates gave lower densities with increasing plastic aggregates percentage.*

Keywords:
High Density Poly Ethylene, Asphalt Concrete Mixture, Indirect Tensile Strength test.

INTRODUCTION

A nation's progress depends on its infrastructure. New materials are used to replace old materials to improve quality, strength and economy. One of the good methods is to use waste plastic in bituminous road construction. Now, the availability of waste plastic usage is great. As the plastic is a part of our daily life. If it is not used again, its current distribution is either through backfilling or burning. Both of them have bad impact on the environment. In this study, using a high percentage of waste plastics reduces the need for aggregate by 12% by weight.

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It also increases the strength and performance of the road. It is important to consider how the asphalt mixture ages, its service life, and during transportation. Eco-friendly road construction is receiving more attention globally. nowadays, types of polymers are utilized to be additives for improving bituminous mixture performances.[1]In a hot climate, mixtures stiffness is increased by polyethylene, which results less strain under the effect heavy traffic .[2] HDPE has the ability of impedance to hot climate. [3]HDPE was added to bituminous mixes from 4 to 8%.

They clarified improvements in Marshall's stability. [4] HDPE modified mixes Optimizes in Marshall's stability. [5] Moghadas Nejad et al. estimated HDPE impact on the mixture at hot climates. It was added from 3% to7%. They showed improvements against rutting. [2] The composite elastic modulus (stiffness) and stress and strain concentration would be greatly increased and decreased, respectively, by a middle coat between aggregates surfaces and the binder.[3] To concentrate on the maturing impact on the research center manufactured example to reproduce field condition, it is essential to account how the bituminous mix combination ages the asphalt. Momentarily, the combination ages as it goes through the plant in creation stage, and during transportation, until it chills off to ordinary temperature momentary maturing). Maturation similarly proceeds at a slower rate over the lifetime of the asphalt (long haul maturing), where response continues at a higher rate in hot environments or throughout the mid-year months when temperatures are higher as it win in Upper Egypt. this work.[4],[5],[6] Short- and long-term thermal aging was examined. That's what they revealed, this test strategy gave off an impression of being delicate to the volumetric extent of bitumen and air void items.[7] It is unbeneficial to HMA rendering , that Stress and strain will be at the moderator between the aggregate and bitumen,.[8] The chemical composition of road hardening is expected , The cohesion of the aggregate is affected.[9] Zainab Z. Ismail et al utilized Shredded plastic wastes to exchange by sand weight in mixtures. [10] 30kg waste plastic recycled in this reserch ,results showed micro-cracks formed in concrete mix.[11]Zainab Z. Ismail used various percentages of water/cement. The compressive strength, process ability and split tensile strength were lower. Somewhat higher than the reference concrete, but much more ductile.[12]. PET aggregate replaced (0%, 7.5%, and 15%) of the natural aggregate. Specimens were ready to laboratory tests. It was for the absorption of water. [13] Utilization of shredded HDPE for replacing by bitumen weight in mixtures. at 165℃ and 30 minutes mixing for determineding the Stability, flow and Quotient of Marshall.[14] Polypropylene fiber specimens were set.it noticed flow decreasing and Stability increasing.[15]Shredded plastic bottles affects in bituminous mixes from 2% to 10% by the binder weight .[16] An adjusted mixture with mix of LDPE, HDPE, and Polypropylene were tested. Results showed improvements in the mixtures. exchange coarse aggregates with polyethylene terephthalate in mixtures led to decrease the bulk density values.[17] Modified asphalt polymer mixtures have shown the same results in improving road pavement performance.[18] The use of plastic materials in the road construction. It assures to be eco-friendly and economical.[19]Ahmadinia et al. Studied the SMA modified mixture with different percentages of PET, and proved that the mixture contain 6% PET has the highest Marshall stability and Marshall Quotient (MQ). Showed that the mixture which contains 6% PET with The elastic modulus 16% higher than the mixture control.[20] (Maharaj, Maharaj, & Mayrand, 2015). Their study tested the effect of different proportions of PET fines and courses [22]found that PET-modified .on specific projects.[21] asphalt mix to perform better Evaluate when using HDPE in asphalt mixes. HDPE modified asphalt can fundamentally develop Marshall stability.[23] Mahesh M Barad (2015) studied modified asphalt .The polymer gives). Bright .performance better than ordinary one. [24] Aforlaetal (2015) He said that Asphalt is expanded by adding waste plastics. It can provide the properties of the asphalt .[25](Blazejowski, 2011) found blending waste plastic into BAC can play a good role in improving waste Flexible road and reduce the pollution of environment.[26] The cohesion between the binder and aggregates do the main part in the acting of the road. Unluckily, all elements have different chemical and physical estates. These estates of asphalt and aggregates also affect each other when both are in close contact. Asphalt modifiers are usually used to improve the asphalt pavement properties. Polymers is a modifier and always utilizes in mixture, polymer particles react with aggregates in hot climate. Laboratory experiments have been conducted to find out the effect of treating composite mixtures on the mechanical properties of asphalt mixture compared with Traditional one.

2. Materials

2.1 Aggregates

Coarse and fine aggregates utilized in this study are crushed dolomite stone, But the sand and mineral filler are natural siliceous sand and limestone dust, respectively. The utilized aggregates physical properties are presented in Table1

2.2 Binder

In this study, AC 60/70 asphalt binder is used as the conventional binder, which is commonly used in Egypt, and its main properties are presented in Table2.

2.3 High-density polyethylene (HDPE)

(HDPE) has been used as a binder additive to improve the properties of bitumen and asphalt mixture as well. It is presented the physical properties of HDPE table 3.

2.4 Waste Collection

Plastic waste collection was from different garbage dumps of the city. For sorting to take (HDPE) wastes, it shredded, and then heated. Semi solid form of plastic obtained was cut and sliced manually, and was used in dry condition.

Table 1. Physical Properties of Aggregate

Test	Results				Standard Test Method
	Aggregate. #1	Aggregate. #2	Sand	Filler	
Bulk Specific Gravity	2.583	2.583	2.57	2.67	ASTM C127 [15] ASTM C128 [16] ASTM D854[17]
Apparent Specific Gravity	2.650	2.705	2.603	2.701	
SSD Specific Gravity	2.623	2.623	2.532	-	
Water Absorption (%)	1.95	2.04	2.89	-	
Los Angeles	27.8	33.2	-	-	ASTM C131 [19]

Table 2. Physical properties of the conventional asphalt binder

Test	Standard	AC 60/70
Penetration (0.1mm, 25◦C, 5 sec)	ASTM D113	64
Softening Point (ring and ball), °C	ASTM D36	46
Flash point (°C)	ASTM D92	320
Ductility (25◦C, 5 cm/min)	ASTM D113	72.06
Specific gravity at 25 °C	ASTM-D70	1.02

Table 3.Physical and mechanical properties of HDPE

Property	Value	Standard Test Method
Density	0.965 g/cm³	ASTM D4883
Melt Index (190°C/2.16 kg)	20 g/10 min	ASTM D1238
Peak Melting Temperature	130 °C	AST M D3418
Tensile Stress at Yield	23 M Pa	ISO 527-2/1A/50
Tensile Strain at Yield	10 %	ISO 527-2/1A/50
Tensile Strain at Break	> 100 %	ISO 527-2/1A/50
Flexural Modulus	920 M Pa	ISO 178
Notched Izod Impact Strength	4.3 kJ/m²	ISO 180/1A
Water absorption, 24 hours (%)	ASTM D570	0.007

3. Experimental Work

3.1. Following tests were performed on aggregates:

* Specific Gravity (ASTM C 127)
* Apparent Specific Gravity of Aggregate Test (ASTM C 128)
* Water Absorption (ASTM D854)

* Asphalt Sample Preparation & Testing

3.2Following tests were performed on binder:

* Penetration test (ASTM D5)

* Softening point test (ASTM D36)

* Specific gravity at 25 °C (ASTM-D70).

* Flash point (°C) (ASTM D92)

* Ductility (25◦C, 5 cm/min) ASTM D113

Each test was replicated three times.

3.3. Following tests were performed on asphalt samples:

*Marshall Stability and Flow Test for optimum bitumen percentage

*Marshall Stability and Flow Test for optimum plastic percentage

*Indirect tensile strength test (IDT)

*Loss of Stability Test
*Long - term Ageing.

3.4. Following tests were performed to Polymer modified asphalt mixtures:

To prepare the HDPE-modified mixtures, in dry case, aggregates and HDPE were heated at 180° C. The hot aggregates were mixed with the shredded HDPE then added the remainder mixture at the same optimum asphalt content (OAC) of the control mixture (5%).

Table (4): Aggregate gradation

Type	Coarse aggregate				Fine aggregate		Design mix gradation	Specification
	Aggregate (1)		Aggregate (2)					
Sieve size (inch)	Passing	%30	Passing	27%	Passing	43%	Passing%	Passing%
1 in	100	30	100	27	100	43	100	100
3/4 in	99.75	29.92	100	27	100	43	99.92	(75 –100)
1/2 in	41.95	12.58	100	27	100	43	82.58	
3/8 in	12.21	3.66	86.68	23.404	100	43	70.06	(45 –70)
No4	1.12	.336	10.478	2.83	99.3	42.69	45.85	(30 –50)
No8	0	0	0.63	.170	95.26	40.96	41.13	(20 –35)
No30	0	0	0.4	.108	61.91	26.62	26.72	(5 –20)
No50	0	0	0	0	35.38	15.21	15.21	(3 –12)
No100	0	0	0	0	12.56	5.4	5.40	(2 -8)
No200	0	0	0	0	4.22	1.81	1.81	(0 -4)

Table 5. Final proportion of each used aggregate

Aggregate Type	Proportions of the proposed mix (%)
Aggregate #2	30
Aggregate #1	22
Sand	43
Filler	5

Table 6. Marshall Mix Design Properties

Asphalt content %	weight of mix in water (WW)	weight of mix in air (WM)	Stability Kg	Flow mm	Specific gravity (GT)	Bulk specific gravity (GM)	air voids (VV)%	volume of bitumen (VB) %	voids in aggregates (VMA) %
4.5	1251.25	710	1038.725	2.67	2.42	2.311	4.5	9.75	14.25
5	1247.23	700	1088.62	3.78	2.40	2.279	5	10.63	15.63
5.5	1229.5	690	1160.741	3.94	2.389	2.278	4.64	11.64	16.282
6	1263.7	705.5	1046.436	3.99	2.374	2.261	4.64	12.54	17.188
6.5	1256.05	709	917.616	4.04	2.35	2.29	2.55	13.70	16.25

4. Marshall Test Results:

It is a simple and low cost standard laboratory test adopted all over the world for design and evaluation of bituminous mixes. This test has been fundamentally used in this study to evaluate the different mixture at different bitumen contents and the parameters considered are: (air voids (VV) %, Specific gravity (GT), volume of bitumen (VB) %, Bulk specific gravity (GM), voids in mixed aggregates (VMA) %, Voids filled with bitumen (VFB)) The test procedure is extensively used in routine test. There are two major features of the Marshall method of designing mixes namely;

(I) Density- voids analysis

(ii) Stability& flow results.

Results

Table (7). Marshall Mixture modified with plastic:

Results of modified mixture with plastic:

Plastic content %	(WW)	(WM)	Stability (Kg)	Flow mm	(GT)	(GM)	(VV)%	(VB) %	(VMA) %
6	1257.4	695	1131.870	3.54	2.311	2.233	3.288	10.4	13.68
8	1238	680.5	1223.652	3.56	2.309	2.21	3.91	10.31	14.22
10	1224.2	660	1247.378	3.76	2.23	2.16	3.13	11.09	14.22
12	1210.95	640	1307.569	3.84	2.201	2.12	3.60	9.89	13.49
14	1240.5	650	1280.036	3.99	2.16	2.10	2.77	9.80	12.57

It resulted that adding HDPE Improved Marshall stability of asphalt mixes. Modified mix with 12% HDPE (by aggregate weight) achieved the maximum stability with an increase more than the conventional mix.

- Indirect tensile strength

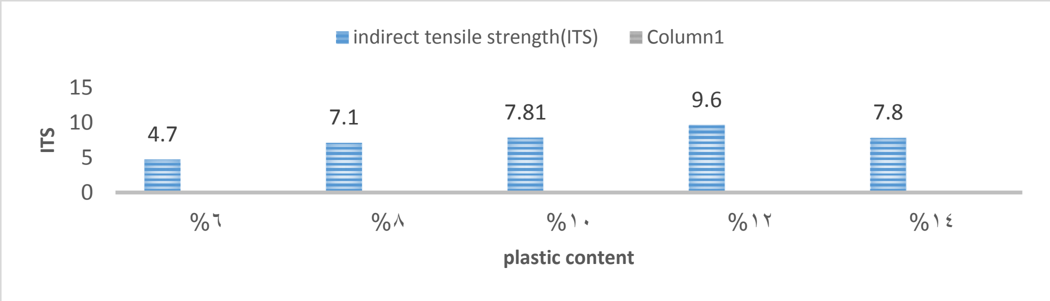
The indirect tensile strength (ITS) values of the traditional and HDPE-modified mixtures are presented in Fig5. The average tensile strength values of all modified dry subsets (at 25 °C) were higher than those of the traditional mixture, which considered as an improvement in mixture stiffness. The 12% HDPE-modified mixture. Therefore, using HDPE as an additive improved the (ITS) values.

ITS values (St) are calculated via utilization this equation:

St = 2P/ (πHD), (kg/cm2), where: P is the failure load in kg, H is the specimen height in cm, and D is the specimen diameter in cm

Table (9) indirect tensile strength results

Sample(plastic)	H (cm)	D (cm)	p(kg)	ITS (kg/cm2)
6%	7	10	527.52	4.8
	7.1	10	501.615	4.5
8%	6.8	10	480.42	7.2
	6.7	10	744.745	7.08
10%	6.9	10	855.807	7.9
	6.8	10	835.9	7.83
12%	6.8	10	1014.22	9.5
	6.7	10	1020.34	9.7
14%	6.7	10	852.03	8.1
	6.8	10	811.37	7.6



Indirect tensile strength results fig (1)

- Loss of Stability Test

Comparing to the traditional mixture as shown in Figure (4). The stability values loss for all additives achieved the requirements which is 25 % maximum according to the Egyptian Code of Practice (ECP, 2008)

Table (10) Stability after & before soaking

Plastic content%	Stability (kg)	Stability after soaking (kg)	Loss of stability (%)
6	1131.870	913.983	19.25
8	1223.652	997.280	18.5
10	1247.378	986.675	20.9
12	1307.569	993.620	24.01
14	1280.036	1013.787	20.8

Marshall Quotient (MQ)

Marshall Test can give an indication of the resistance of mixtures against rutting, Marshall Quotient (MQ) calculated from dividing the stability over the flow .The higher MQ values indicate higher mixtures' stiffness and consequently higher resistance to permanent deformation.[27].

$$MQ = MS \div MF$$

Where:
MQ = Marshall Quotient.
MS = Marshall Stability.
MF = Marshall Flow.

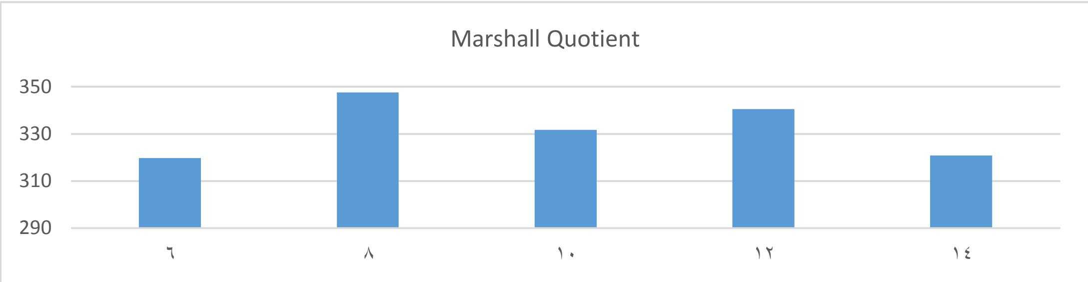


Table (11) Marshall Quotient

Plastic content %	stability	flow	Marshall Quotient
6	1131.870	3.54	319.728
8	1223.652	3.56	347.628
10	1247.378	3.76	331.749
12	1307.569	3.84	340.513
14	1280.036	3.99	320.811

Fig (2) Marshall Quotient results

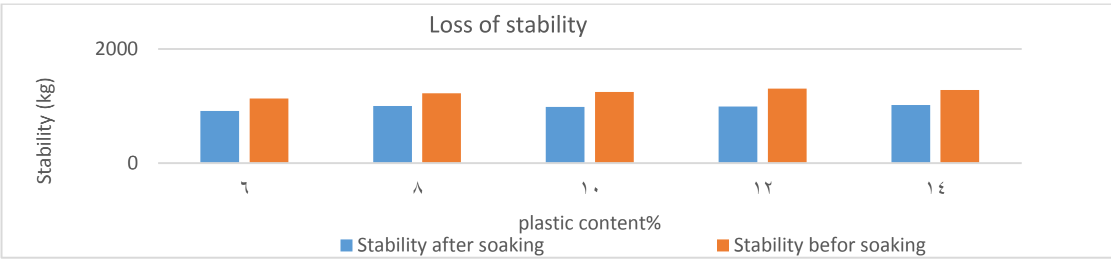


Fig (3) Loss of stability results before and after soaking

Figure. 4 shows the percentage of the average loss of stability values for the traditional and HDPE-modified mixtures. It can be observed that the increasing proportion of HDPE leads to a decrease in the loss of stability percentage and the 12% HDPE-modified mixture achieved the lowest loss of stability.

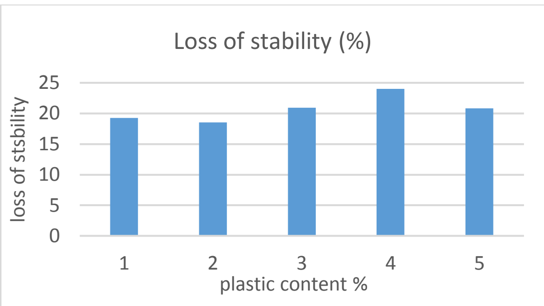


Fig (4) loss of stability results

Long - term Ageing.
In case of long term ageing process, (24 hour , 72 hour) Marshall stability values for traditional mixtures are higher comparing with that for plastic mixtures.it is meaning that the modified asphalt mixtures with plastic was low harden during the process of ageing compared with traditional one.

The indirect tensile strength (IDT) and Marshall Stability values. As will be discussed in the following sections table (12), table (13).

Table (12) Stability value after heating at 90 °C oven for (24h, 72hr)

sample	After heating (24h) Stability value	After heating (72h) Stability value
Ordinary mixture	957.587	880.966
Plastic mixture (12%)	1111.708	1053.485

Table (13) indirect tensile test after heating (24h, 72)

sample	Indirect tensile test after heating (24h)	Indirect tensile test after heating (72h)
Ordinary mixture	6.6	6.9
Plastic mixture (12%)	7.1	7.3

The results of indirect tensile strength (IDT) and Marshall Stability values after ageing tests (heating 24hr, 72hr). As will be discussed in the following sections fig (12), table (13)

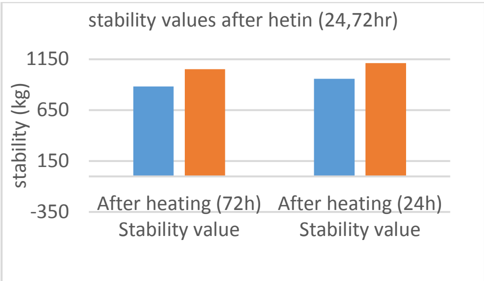


Fig (5) Stability value after heating (24h, 72)

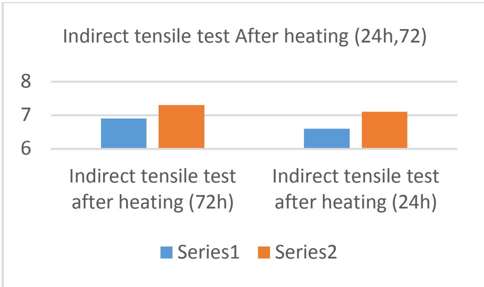


Fig (6) indirect tensile test after heating (24h, 72)

Physical tests were done on traditional and HDPE-modified binders having different HDPE content (rotational viscosity tests) the results of the Brookfield RV tests presented in Figure. 7 show that the binder viscosity increases with the increasing of HDPE content. A significant improvement in the viscosity was observed with the increase of HDPE concentration. However, in the extreme cases of adding14% HDPE, the viscosity increased to 4998 MPa, which do not satisfy (ASTM D6373) criterion for asphalt binder workability (3000 MPa)

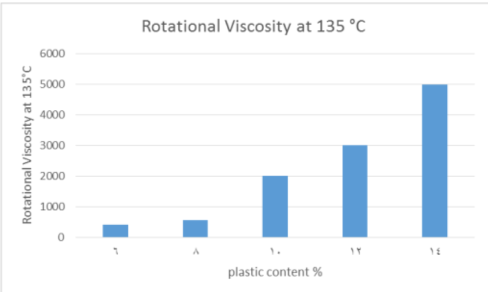


Fig.7. Rotational Viscosity of modified binder

Conclusion and Recommendation

High-density polyethylene (HDPE) and the aggregates in dry condition both were heated at 180° C. The hot aggregates were blended with the shredded HDPE then added the remainder mixture at the same optimum asphalt content (OAC) of the control mixture (5%). It added to the mixture from 6% to 14% by aggregates weight. The obvious results in this paper as follow:

•The higher presentation of modified mixture was done at 12% of high-density polyethylene (HDPE) by aggregates weight.

• HDPE modified mixture additive Improved the mixes stiffness and consequently its tendency to permanent deformation.

•Laboratory experiments indicated improved mixture performance in Marshall Stability, Marshall Quotient, Indirect Tensile Strength, and Unconfined Compressive Strength of the (HDPE) modified asphalt mixture.

•The rate of hardening of high density polyethylene modified asphalt mixtures is less than that for traditional asphalt mixtures considering long term ageing process. This may be because of the high density polyethylene layer has minimize the effect of ageing of bitumen because of its plastic properties and its higher resistance for temperature compared with bitumen material.

•Because of lesser density of plastic aggregates, asphalt samples made of replaced plastic aggregates showed lower densities with increasing plastic aggregates percentage.

• Since the greater part of the asphalt is used to fill the pores of the plastic aggregate, lower Quantity of asphalt is available to fill the voids of asphalt, increasing the asphalt

mixture percentage of voids.
•Stability of the mixes showed increasing at 12% replacement than sudden decrease in stability was watched, stability decreasing might be a direct result of plastic aggregate higher porosity.

• The greater part of the binder was utilized in filling plastic aggregates pores leaving behind a not enough quantity of bitumen to make a stronger bond. The plastic aggregates compressibility was more prominent than regular aggregates.

• Flow value of the mixes has no high effect when adding HPDE with various percentage. This referred to bitumen physical properties, but at mixture with 14% HDPE, flow value had a little high.

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