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Evaluate the Effect of Waste Ground Rubber Tire Powder in Hot Mix Asphalt

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***Abstract*—In the present study, the effect of waste ground rubber tire powder (WGRTP) modifier on various mechanical properties such as Marshall stability, flow, Marshall quotient (MQ), bulk specific gravity, air voids, voids filled with bitumen (VFB) and percent voids in compacted mineral aggregates (VMA) of asphalt mixture has been evaluated. The Marshall tests of the polymer modified asphalt mixture, prepared through dry process, indicated the optimum waste polymer modifier content to be 5% by weight of mix. The waste polymer modified asphalt mix containing 5% WGRTP showed considerable improvement in various mechanical properties of the mix compared to the conventional asphalt mixture. The appropriate amount of the added WGRTP was found to be 5% by weight of aggregate. This percentage results in the maximum level of stability.**

Keywords—Hot mix asphalt; Waste ground rubber tire powder; Dry process; Marshall test method

I. INTRODUCTION

The construction and maintenance of roads consume large amounts of aggregates, which typically account for more than 90% by weight of the asphalt mixtures. Pavement engineers have realized that there is a broad range of technically proven, cost-effective reuse and recycling options available to conserve natural resources and extend landfill life. Now waste rubber has become one of the most recycled products in the world and commonly used component for hot mix asphalt (HMA). Reuse and recycling of waste rubber results in a substantial reduction in the quantity of new aggregates required for road construction work, extending the life of non-renewable aggregate resources. Reuse and recycling also reduces the volume of reusable material that is placed in landfills, where it takes up ever-dwindling space that is better reserved for domestic waste, thereby extending the life of the landfill and decreasing the need for new landfills. This is one way of getting the road construction industry on track towards sustainable construction practices.

The primary reason for using waste rubber in asphalt pavements is that it provides significantly improved engineering properties over conventional asphalt pavements. As demonstrated by various researchers, waste rubber have reduced fatigue and reflection cracking, greater resistance to rutting, improved aging and oxidation resistance and better chip retention due to thicker binder films [1-7]. Also asphalt rubber pavements have been demonstrated to have lower maintenance costs [8-9], lower noise generation [10-12], 2006), higher skid resistance and better night-time visibility due to contrast in the pavement and stripping [10].

Use of waste rubber in asphalt generally has two distinct approaches. One is to dissolve crumb rubber in the bitumen as binder modifier, the other to replace a portion of fine aggregates with ground rubber that is not fully reacted with the bitumen. These are referred to as the ‘wet process’ and the ‘dry process’, respectively. Modified binder from the ‘wet process’ is termed ‘asphalt rubber’; asphalt made by the ‘dry process’ is ‘rubberized asphalt’ [13].

The main differences between these processes include size of rubber; in the dry process rubber is much coarser than wet process rubber, amount of rubber; the dry process uses rubber 2 to 4 times as much as the wet process, function of rubber; in the dry process the rubber acts more like an aggregate but in the wet process it acts more like the binder, and finally the ease of incorporation into the mix; in the dry process no special equipment is required while in the wet process special mixing chambers, reaction and blending tanks, and oversized pumps are required [14].

Several researches have focused on the reuse of waste tire rubber in asphalt pavements produced by dry process to improve its engineering properties. Fernandes et al. [15] have concluded that rubberized asphalt mixtures produced by dry process, have increased the elasticity of the mixture; it could enhance the bonding between binder and aggregates resulting in an increase in fatigue life, and resistance to rutting, and could lead to a reduction of the thermal and reflecting cracking of these mixtures. Khalid and Artamendi [16] have revealed that the control of rubber particles and asphalt interaction could not be done in an easy way since there was immediate mixing between aggregates and asphalt. When these mixtures were established correctly, such pavements were better for icy road conditions. Kettab and Bali [17] indicated that when rubber with particle size higher than 2 mm was added to asphalt mixtures, the compaction and strength characteristics were improved as the rubber fills the existing voids within the granular skeleton. Khalid and Artamendi [16] showed that the addition of rubber at (10–15)% (by weight of the asphalt) by dry process caused a reduction in penetration into bitumen and softening point, while viscosity increased with CR content and decreased as temperature was elevated. According to Fernandes et al. [15], rubberized dense asphalt mixtures has resulted in lower Marshall stability values than the virgin asphalt, while flowability increased with the increase of rubber content. Mashaan et al. [18] presented and discussed the findings from some of the studies on the use of crumb rubber in asphalt pavement. They showed that, it aspires to consider crumb rubber modifier in hot mix asphalt to improve resistance to rutting and produce pavements with better durability by minimizing the distresses caused in hot mix asphalt pavement.

Although the dry process has the advantages concerning the lower costs involved and the higher amount of rubber to be used, the process is still need more investigation due to the irregular performance of some experiment sections built with it [19]. This paper presents the results of an experimental investigation studying the behavior of HMA using waste ground rubber tire powder produced by dry process. The physical properties of waste ground rubber tire powder, bitumen, and crushed aggregate were first investigated. The optimum bitumen binder content of the polymer modified asphalt mixture was found using Marshall Mix design. The effect of waste ground rubber tire powder (WGRTP) modifier on various mechanical properties of the polymer modified asphalt mixture has been evaluated.

II. Materials and Experimental program

A. Materials

The materials that have been used in the current study are waste ground rubber tire powder (WGRTP), bitumen, and crushed granite aggregate. Four types of available crushed stones classifies as 0/19, 0/12.5, 0/9.5 and 0/4.75 are locally known by Foliya, Adasia, Simsymia and Trabia respectively were used to obtain the specified gradation. Table 1 displays the selected gradation of the used aggregates and Table 2 shows their properties. The bitumen used for this study was 60/70 penetration grade. The physical properties of the used bitumen are available in Table 3. The applied WGRTP were used as partial replacement for aggregates. The gradation of WGRTP is displayed in Table 4.

TABLE 1. The gradation of aggregates.

Sieve size (mm)	0/19	0/12.5	0/9.5	0/4.75
19	100.00	100.00	100.00	100.00
12.5	27.56	49.09	99.76	100.00
9.5	13.31	13.70	97.17	100.00
4.75	2.27	2.50	24.34	99.30
2.36	0.73	0.33	6.93	84.76
1.20	0.20	0.33	1.59	66.48
0.60	0.15	0.32	1.47	52.51
0.30	0.15	0.32	1.47	24.71
0.18	0.15	0.32	1.17	9.19
0.075	0.15	0.32	1.08	8.20

TABLE 2. Physical properties of the crushed aggregates.

Properties	Test method	0/19	0/12.5	0/9.5	0/4.75
Abrasion (%)	ASTM C-131	28.4		-	-
Bulk dry S.G.	ASTM C-127	2.52	2.61	2.52	2.52
Bulk SSD S.G.	ASTM C-127	2.57	2.65	2.56	2.57
Apparent S.G.	ASTM C-127	2.64	2.73	2.64	2.64
Absorption	ASTM C-128	1.72	1.76	1.82	1.72

*Test was conducted on Sample Type B which is 2500 g passing sieve size 19 mm and 2500 g passing sieve size 12.5 mm.

TABLE 3. Physical properties of 60/70 penetration grade paving bitumen.

Test	Test Method	Unit	Value	ASTM limits
Penetration	ASTM D- 5-97	1/10 mm	60.67	60-70
Flash point	ASTM D-92	°C	265	Min 250°C
Fire point	ASTM D-92	°C	282	-
Ductility	ASTM D-113	cm	139	Min 100
Softening point	ASTM D-36	°C	47.9	45-52
Specific gravity	ASTM D-70	-	1.02	1.00-1.05

TABLE 4. The gradation of WGRTP.

Sieve size (mm)	Percent passing
0.063	100
Pan	0

B. Experimental program

- *Aggregate Gradation*

The first phase in any mix design is the selection and combination of available aggregates to obtain a gradation within the required limits. Available crushed stones were combined together using a trial and error method for gradation design to obtain the specified gradation. The proportions of aggregate 0/19, 0/12.5, 0/9.5 and 0/4.75 used in the combination for mix designing were found to be 18:32:21:29 respectively. Note, however, that the first trial may not always meet the specified limits. In such cases, other combinations must be tried until a satisfactory one is obtained. Table 5 shows the results of a sieve analysis and the computation method of samples from the used materials. The gradation curve for bituminous concrete mix versus the limits, according to ASTM standards is given in Fig. 1.

TABLE 5. COMPUTATION OF PERCENTAGES OF DIFFERENT AGGREGATE SIZES.

Sieve size (mm)	Percent passing									ASTM gradation limits*	
	0/19		0/12.5		0/9.5		0/4.75		Total	Upper limit	Lower limit
	Before	After x 0.18	Before	After X0.32	Before	After X0.21	Before	After X0.29			
19.00	100.00	18.00	100.00	32.00	100.00	21.00	100.00	29.00	100.00	90	100
12.50	27.56	4.96	49.09	15.71	99.76	20.95	100.00	29.00	70.62	67	85
9.50	13.31	2.40	13.70	4.28	97.17	20.41	100.00	29.00	56.08	56	80
4.75	2.27	0.41	2.50	0.80	24.34	5.11	99.30	28.80	35.12	35	65
2.36	0.73	0.13	0.33	0.10	6.93	1.45	84.76	24.58	26.27	23	49
1.20	0.20	0.04	0.33	0.10	1.59	0.33	66.48	19.28	19.75	15	37
0.60	0.15	0.03	0.32	0.10	1.47	0.31	52.51	15.23	15.66	8	28
0.30	0.15	0.03	0.32	0.10	1.47	0.31	24.71	7.17	7.60	5	19
0.180	0.15	0.03	0.32	0.10	1.17	0.25	9.19	2.66	3.04	3	14
0.075	0.15	0.03	0.32	0.10	1.08	0.23	8.20	2.38	2.74	2	8

*SOURCE: *Annual Book of ASTM Standards, Section 4, Construction,* Vol. 04.03, Road and Paving Materials; Pavement Management Technologies, American Society for Testing and Materials, Philadelphia, PA, 2012.

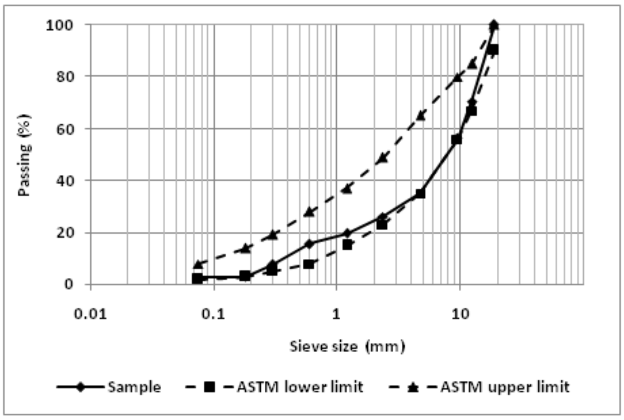


Fig. 1. *Gradation curve of bituminous concrete mix*

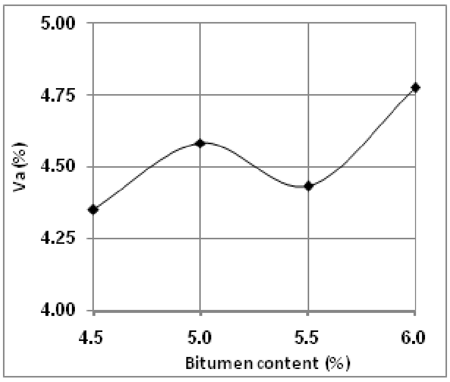
▪ *Preparation of specimens*

The Marshall mix design procedure as specified in ASTM D1559-89 was used for determining the optimum binder content (OBC) that should be used in the mixture to give the proportions of the different materials to be used in producing the conventional hot-mix mixture that satisfies the requirements of the given specifications. The Marshall specimens were prepared by adding 4.5%, 5.0%, 5.5% and 6.0% of asphalt (by weight of mix) into the hot aggregate. Three identical specimens for each percentage were fabricated and the average value is reported. The amount required for each specimen is about 1200 g. The volumetric properties were then determined as shown in Fig. 2 to obtain the optimum binder content, which was found to be 5% (by wt. of mix) with 5.45% air voids, 4.8 bulk specific gravity and 4.75 kg stability.

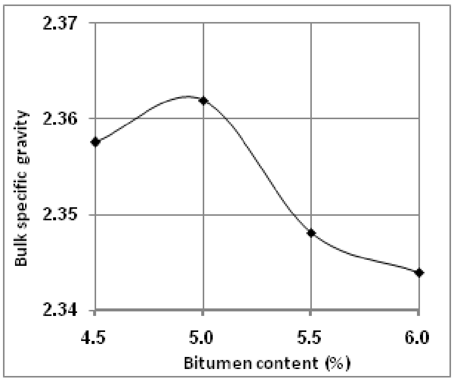
Waste polymer modified bituminous concrete mixes were prepared by mixing varying amounts of WGRTP (5%, 10% and 15% by weight of mix) into the pre-heated aggregate at 150 - 160°C, followed by addition of the bitumen using the same optimum binder content as was determined for conventional mixes (5% by weight of mix). The bituminous mix was then placed in a Marshall mold and compacted by applying 75 blows on each side in the above temperature range. The samples were cooled at room temperature for a day and then placed in water at 60°C for 30 min. The Marshall stability was determined using Marshall test apparatus. The various engineering properties of modified bituminous mixes were evaluated to assess the effect of adding waste polymer modifier on bituminous mixes. The mix proportions were calculated for one sample weight 1200 g and presented in Table 6.

TABLE 6. MIX PROPORTION FOR ONE SAMPLE (1200 GRAMS).

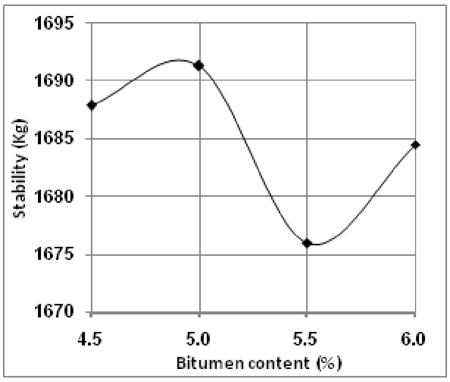
Job mix	WGRTP		Bitumen		Aggregate		Total (g)
	Proportion (%)	Weight (g)	Proportion (%)	Weight (g)	Proportion (%)	Weight (g)	
Mix 1	0	0	5.0	60	95	1140	1200
Mix 2	5	60	5.0	60	90	1080	1200
Mix 3	10	120	5.0	60	85	1020	1200
Mix 4	15	180	5.0	60	80	960	1200



(a) Bulk Air void value versus bitumen content



(b) Bulk specific gravity value versus bitumen content



(c) Stability value versus bitumen content

Fig. 2. *Marshall test property curves for conventional hot-mix mixture*

III. RESULTS AND DISCUSSION

A. *Marshall Stability*

The stability is defined as the maximum load resistance that the specimen will achieve at 60°C under specified conditions. The mixture should have an adequate mix stability to prevent unacceptable distortion and displacement when traffic load is applied (Garber and Hoel, 2009). Fig. 3 illustrates the Marshall stability value of the conventional and modified mixes versus the WGRTP content. As can be seen, the Marshall stability of modified mixes increases by about 12.73% with addition of the modifier up to 5%, but decreases as the percentage of the modifier is further enhanced from 10% to 15%. The increase in stability by adding rubber to the hot mix asphalt is attributed to better adhesion developing between the materials in the mix. However, further increase in the modifier content results in a decrease in the stability of the modified mixes, which may be ascribed to reduced adhesiveness of the mix. Therefore, the optimum percentage of modifier was selected to be 5% by weight of aggregate.

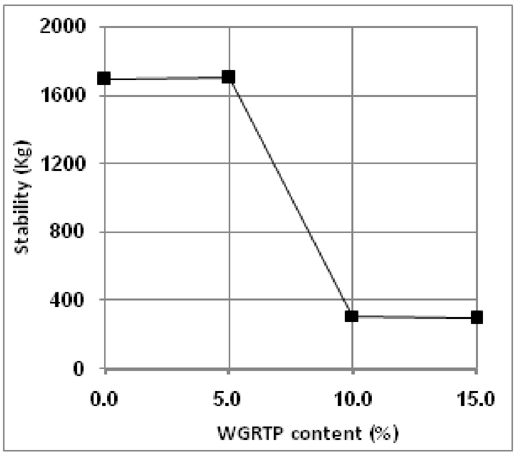


Fig. 3. *Stability value versus WGRTP content.*

B. *Marshall Flow*

The flow values of conventional and the modified mixes at various WGRTP percentages are shown in Fig. 4. The flow initially increases with addition of the modifier up to 5%, but decreases gradually as the percentage of the modifier is further enhanced from 5% to 15%, which can be ascribed to the fatigue cracking of the mix due to the increased stiffness.

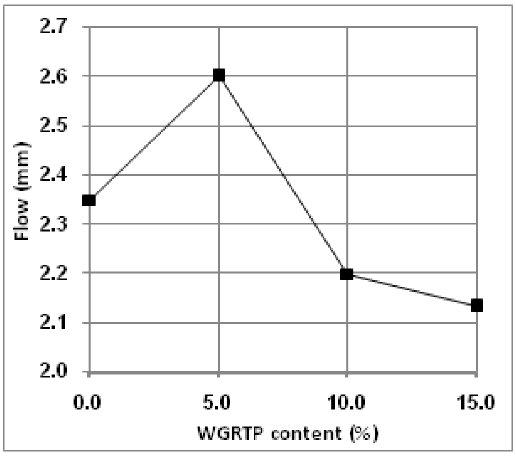


Fig. 4. *Marshall Flow value versus WGRTP content.*

C. *Marshall Quotient*

Since the Marshall Quotient (MQ) is an indicator of the resistance against the deformation of the bituminous mixture and can be calculated as the ratio of stability to flow [21-24]. MQ values are calculated to evaluate the resistance of the deformation of the specimens. As Fig. 5 shows, the Marshall Quotient slightly decreases with addition of the modifier up to 5%, and then obviously decreases as the percentage of the modifier is further enhanced from 5% to 15%. Therefore, it can be concluded that the bituminous mixture with high WGRTP content has lower stiffness and worse resistance against serious deformation as a result of heavy loading.

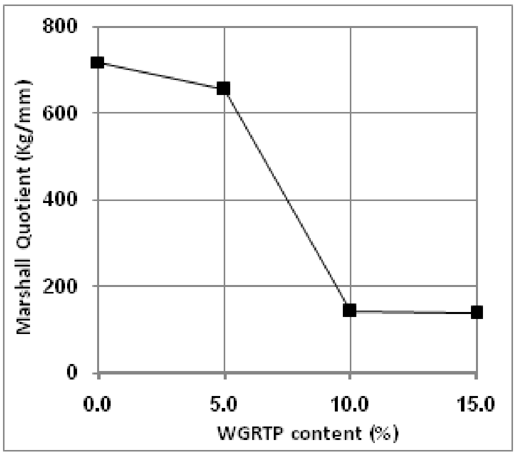


Fig. 5. *Marshall Quotient value versus WGRTP content.*

D. Bulk Specific Gravity

Regardless of the WGRTP content, the bulk specific gravity of the WGRTP -mixture was lower than that of the control mixture. As Fig. 6 illustrates, any increase in WGRTP content reduces the bulk specific gravity of the mix. The resulting decrease in the bulk specific gravity value in case of WGRTP -mixtures is due to the lower specific gravity of the WGRTP in comparison with the mineral aggregates.

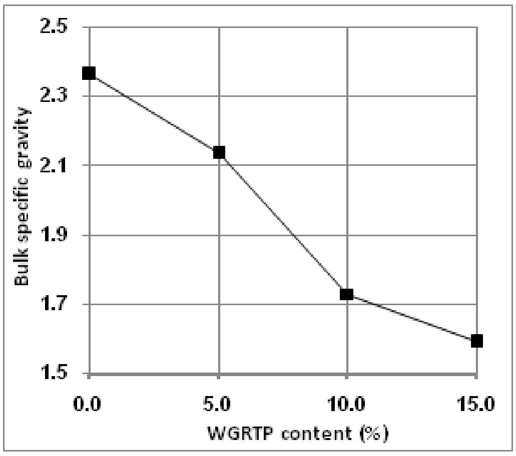


Fig. 6. *Fig. 6. Bulk specific gravity value versus WGRTP content.*

E. Air Void

The percent air voids (Va) in compacted mixture is the percent ratio between the volume of the small air voids between the coated particles and the total volume of the mixture. The air void is one of the vital bituminous mixture parameters used for pavement design and the achievement of optimum asphalt content. Excessive air voids cause cracking due to the insufficient asphalt binder coating the aggregate, while low air voids may induce more plastic flow (rutting) and asphalt bleeding (El-Maaty and El-Moher, 2015; Chen et al., 2009; Ahmedzade and Yilmaz, 2008; Sengoz and Topal, 2007). As Fig. 7 shows, increasing the WGRTP content in the mixture results in less air voids in the mixture. The decrease in air voids upon increasing WGRTP content depends partially on the total filler content. The decrease in air voids upon increasing WGRTP content depends partially on the total filler content. The air voids decrease slightly due to partial replacement of mineral aggregates by WGRTP which increases the amount of filler resulting in reduction the void spaces between the granular particles in the compacted mix.

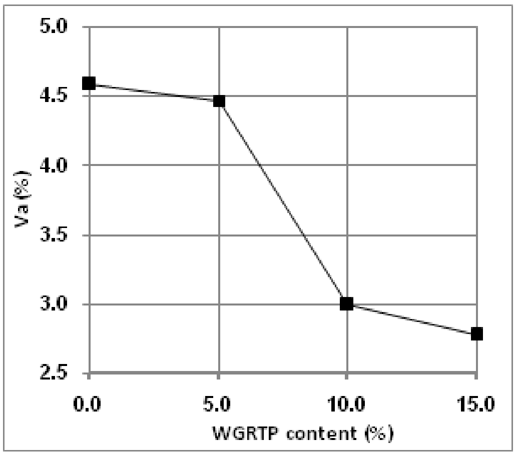


Fig. 7. *Air void value versus WGRTP content.*

F. Voids in Mineral Aggregate

The percent voids in compacted mineral aggregates (VMA) is the percentage of void spaces between the granular particles in the compacted paving mixture, including the air voids and the volume occupied by the effective asphalt content. VMA provide space for binder films on the aggregate particles. The durability of the mix increases with the film thickness on the aggregate particles (Ahmadinia et al., 2011). Fig. 8 demonstrates the effect of WGRTP contents on voids in compacted mineral aggregates.

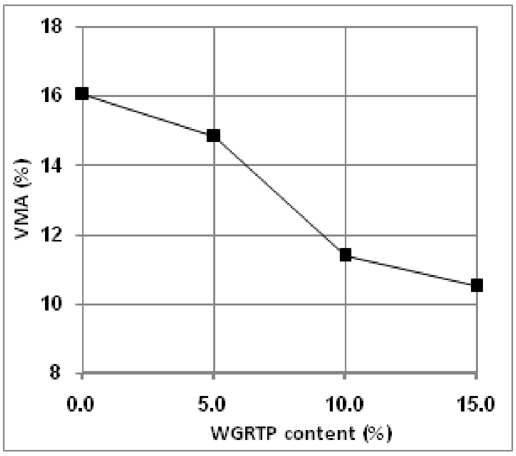


Fig. 8. *Void in mineral aggregate (VMA) value versus WGRTP content.*

As the figure displays, all VMA values decrease by increasing the WGRTP content. The resulting decrease in the VMA value is due to partial replacement of mineral aggregates by WGRTP which increases the amount of filler resulting in reduction the void spaces between the granular particles in the compacted mix. Lower values of VMA result in less spaces to accommodate the required asphalt to produce good coating and durable mix.

IV. Conclusions

The effect of waste polymer modifier (ground rubber tire powder) on various mechanical properties of the bituminous concrete mixtures was evaluated. Summarizing the overall conclusions achieved through this research, the significant findings of the current study are as follows:

- With the introduction of more WGRTP content into the mixture, the Marshall stability first started to increase, but then slumped after 5%. However, the Marshall Flow started with an initial increase, which was followed by a decrease with the introduction of more WGRTP into the mixture.
- Due to their low MQ, the WGRTP decreased the stiffness level of the mixture declining its resistance level against permanent deformation.
- Adding WGRTP to the mixture decreases the air voids of the mixture and its bulk specific gravity.
- The appropriate amount of the added WGRTP was found to be 5% by weight of aggregate. This percentage results in the maximum level of stability.
- It can be concluded from the outcomes of the study that the effects of WGRTP on air voids, bulk specific gravity and Marshall Stability of the mixture are significant.

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