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Use of Recycled Material in WMA- Future of Greener Road Construction

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Abstract

Sustainable road construction practice requires an asphalt mix technology which is environmental friendly, energy efficient, economical and protective for humanity and health. India and many other countries are using Hot Mix Asphalt (HMA) technology for asphalt road construction. HMA has several disadvantage like high production temperature (155˚C to 165˚C), which increases Green House Gas (GHG) emissions such as CO_2, SO_2 and NO_x etc. These emissions increase global warming and also severely affect the respiratory system of paving crew workers. Warm Mix Asphalt (WMA) technology reduces the mixing and compaction temperature by around 30˚C in comparison to HMA. WMA has many advantages over HMA like fuel saving, reduced emissions, improved visibility at paving site, more incorporation of Reclaimed Asphalt Pavement (RAP) due to lower secondary ageing of aged binder and the ambient working environment. As it is well known that major demand of road construction industry is the continuous and economical supply of construction materials. This demand is satisfied by production of virgin aggregate and bitumen, which depletes natural limited resources and generate harmful emissions. There is a desire need of alternate material which can prevent the use of natural resources. One alternate material is Reclaimed Asphalt Pavement (RAP) which can solve purpose. The recycling approach was started in the beginning of twentieth century and from then many researchers are continuously improving the technology. Researchers found two major issue with use of RAP in asphalt mixes such as high emission during mixing of RAP with virgin aggregate and premature cracking due to aged binder. WMA may resolve these two issues by reducing binder's viscosity at lower production temperature and thereby reducing high emissions during production of asphalt mix and secondary aging of binder. Some WMA additives also works as rejuvenators which provide good quality mixing with aged RAP. This paper discusses the WMA technology, it's classification, mix design guidelines for WMA, history of recycling, use of RAP and Reclaimed Asphalt Shingles (RAS) into WMA and role of rejuvenators in WMA.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: Warm Mix Asphalt (WMA); Reclaimed Asphalt Pavement (RAP); Reclaimed Asphalt Shingles (RAS); rejuvenators.

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1. Introduction

Sustainable road construction practice is founded on four pillars: (a) satisfactory performance of pavement during its design life, (b) environment friendly technology, (c) wise utilization of money and (d) construction should be favorable to human safety, health and comfort. Worldwide, GHG emissions are estimated at 34.8 billion tons annually. India is the world's fourth largest country in annual emission levels of CO_2 gas. As shown in figure :1, from 2000 to 2016 India and china's CO_2 emission levels are increasing whereas there is remarkable decrease in the emission level of USA and EU28. This decrement is due to the inclination of USA and EU28 to various eco-friendly technologies.

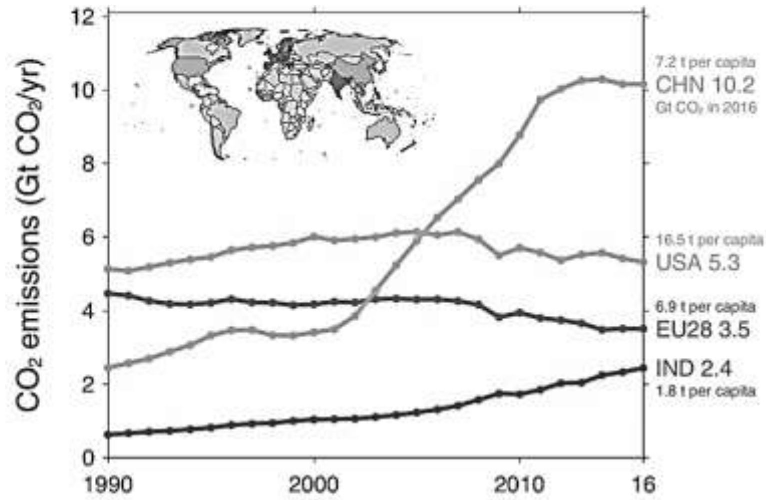

Figure 1: CO2 emissions for India, China, U.S. and Europe.
(Source: CDIAC, Global Carbon Project, and UN.)

As a result of United Nation's discussion on environment in the year 1992, "KYOTO ACCORD" was formulated in 1997 which combines signatory states to reduce GHG levels to 1990 levels whereas Germany established "The German BITUMEN Forum" to limit the asphalt fumes. In this direction Germany took strep to reduce the emissions from asphalt mix plants and the first application on a public road was carried out in Germany in 1999 using the Aspha-min® zeolite system. After the success of WMA in Europe, USA sent a committee to Europe in 2002 for study and observation of WMA in seven European countries. Then, presentations were performed by the representatives of the European companies at the NAPA Annual Convention in 2003. During the year 2003 at the National Center for Asphalt Technology (NCAT), National Asphalt Pavement Association (NAPA), the Federal Highway Administration (FHWA) and some warm mix technology suppliers began a funded research in cooperation to investigate different methods by which asphalt mixture production and placement temperatures could be decreased [Kheradmand et al., 2010]. The first trial to construct the road in US in 2004, Canada in 2005, china in 2007, South Africa in 2008, India in 2009 and Brazil in 2010 [Kumar and Chandra, 2016]. A study indicated significant average reduction in GHG emissions due to use of WMA technology as compare to HMA is shown below in figure 2.

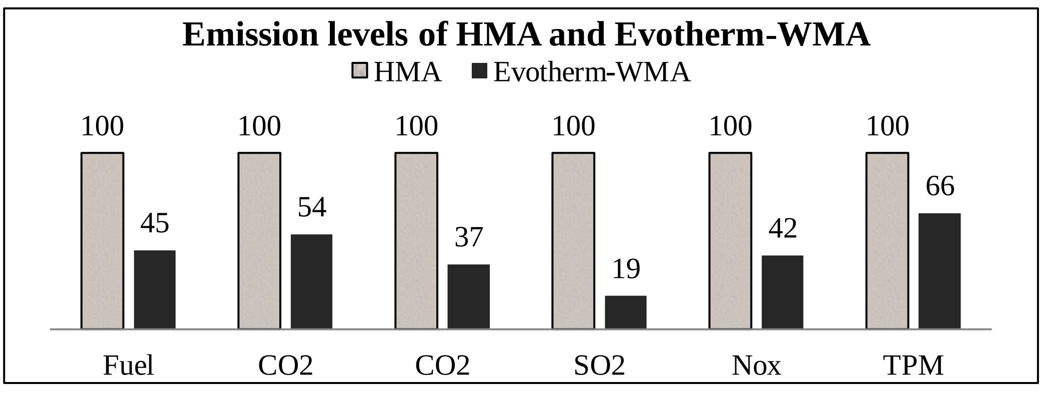

Figure 2. Average percentages of fuel and emission as compare to HMA [Gandhi and Everett, 2014].

According to NCHRP 9-47 A report, a reduction of 11.11 ˚C in temperature results into 20% reduction in CO_2 emissions and fuel saving of 21%. Another study reveal that 22˚C reduction in HMA plant temperature results into reducing airborne exposure of harmful gases (Polycyclic Aromatic Compounds and Total Organic matter) [Cavallari et al., 2012].
Reclaimed Asphalt Pavement (RAP) and Reclaimed Asphalt Shingles (RAS) are the two main recyclable resources of bitumen. As per the survey conducted by Hansen & Copeland (2015) in association with Federal Highway Administration (FHWA) and National Asphalt Pavement Association (NAPA) in United States, the total production of asphalt mix for the construction year 2014 was 352 million tons. Around 72 million tons of RAP was used by contractors in the same year which shows more than 20% RAP had utilized. In this way, RAP is estimated to conserve around 20 million barrels of asphalt binder along with replacing some 68 million tons of virgin aggregate. Another finding of the same survey stats that around 2.0 million tons of RAS have utilized in road construction which is 15% of the total waste shingles (i.e. 13.2 million tons) available every year. The estimated saving was around $2.8 billion due to utilization of RAP and RAS. Hence, the use of reclaimed materials has significant impact on economy of country and sustainability of nation's pavement infrastructure.

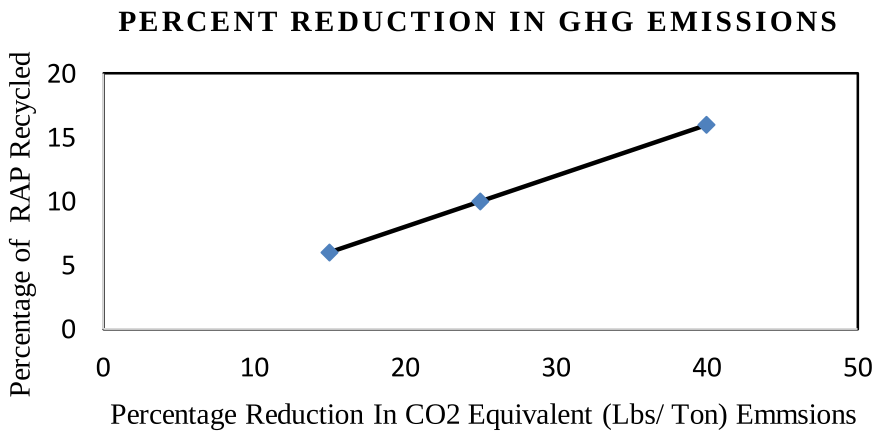

Figure 3: Percentage reduction in GHG emissions [Chappat and Bilal, 2003].

Figure: 3 indicates the reduction in CO_2 emissions as RAP replaces the processing emissions associated with virgin aggregate and bitumen. Hence the use of recycling and low temperature asphalt mix technology combination is the need of time. By reducing mixing and compaction temperature of asphalt mixes these emissions can be lowered by some amount subjected to the condition that aged binder should mix with virgin binder properly. WMA technologies are largely adopted with RAP and RAS recycling and WMA additives like wax facilitates reduction in viscosity of binder at lower level thereby providing adequate mixing [Advanced Asphalt Technologies, 2012]. Rejuvenators also facilitates the same action in RAP incorporated WMA mixes.

2.0 Mix Design of WMA according to IRC 101: 2014:

Indian Road Congress 101, 2014 state that the mix design of WMA will be same as of HMA (except the mixing and laying temperatures) i.e. the Optimum Bitumen Content (OBC) will be found out same as of HMA. However, following tests are proof checks for the performance of WMA:

Table 1: Mix design criteria of WMA.

Sr. No.	Criteria	Guidelines	Code provisions
1	Aggregate Coating	95% of coarse aggregate should be fully coated	AASTHO T 195
2	Compactibility	Ratio of air voids (Ra) should lie in between 0.9 to 1.0.	AASTHO T 245 for JMF preparation
3	Moisture sensitivity	TSR value of 80% is required for WMA specimens at percent air voids are 7+/-0.5%.	AASTHO T 283.

- Moisture susceptibility of WMA is a major issue in this technology because there are some chances that moisture may retain within the aggregates at lower mixing and compaction temperature.
- IRC 101: 2014 specify that WMA additive should also work as antistripping agent and if not so then it is mandated to use hydrated lime or some liquid antistripping agent. However, in case of foaming technology use of liquid antistripping agent or lime may be detrimental.

It is recommended by IRC 101: 2014 that above parameters are evaluated in the laboratory first and then a field trial of length 500 m should be constructed using WMA technology and the results from there should be confirmed from laboratory test results. Although there are some concerns related to WMA technology some of them are listed below:

- Incomplete drying of aggregates leads to moisture susceptibility.
- Reduced aging of binder may lead to early rutting.
- Developing a mix design process that works for all WMA technologies.
- Keeping track of new WMA technologies and their field implementation.
- Long Term performance analysis of already constructed WMA pavement in India.
- Improving plant burner efficiencies.

3.0 History of Recycling Technology:

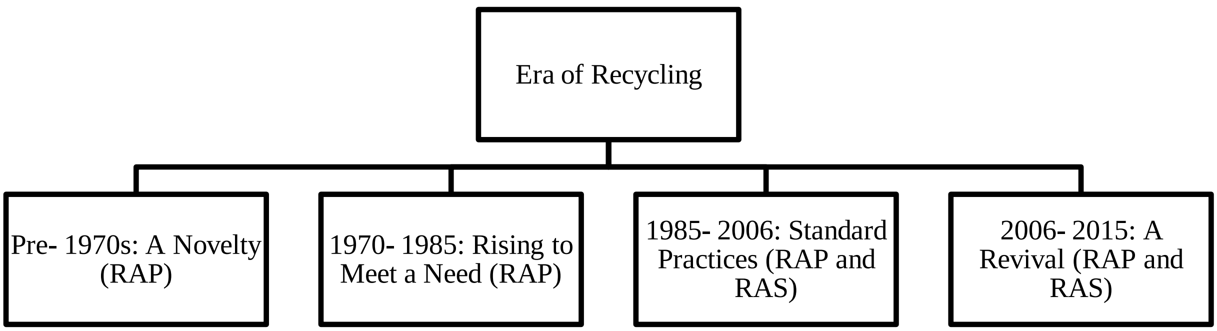

Figure 4: Era of recycling

Pre- 1970s: A Novelty (RAP): In the beginning of twentieth century Warren Brother Co. employed recycled asphalt mixes. This was the first step to use reclaimed asphalt pavement. Later in Singapore in the year 1931, recycling was used as a mean of conserving petroleum for rehabilitating a prematurely distressed pavement. This pavement lasted for 14 years until World War-II. In India the first reclaimed asphalt pavement was constructed in 1948 which serves uninterrupted for 30 years.

1970- 1985: Rising to Meet a Need: In this time period high amount of RAP was used around on an average 75% and more RAP. To soften the stiffer mixes, rejuvenator have been used widely. Some examples of rejuvenators used at that time are: Cyclogen L (recycling oil), AR- 2000 + Extender Oil, Paxole (softening agent), E.A. 11-M (Emulsified Asphalt), Cyclopave (Recycling Oil) [Newcomb et al., 1993].

In era 1985- 2006: Standard Practices (RAP and RAS), In U.S., the use of RAP and RAS had become a normal practice as contractors are getting cost saving by it. By the advent of Superpave design system, where aggregate and binder selection was based on some parameters, the incorporation of RAP has a confusing effect for agencies and contractors hence it deaccelerates the adaptation and popularity growth rate of RAP and RAS into asphalt mixes. In the late 1990s a NCHRP project 09-12 was undertaken by [McDaniel et al., 2001] for incorporation of RAP into Superpave system.

2006- 2015: A Revival (RAP and RAS) In this phase an important step was taken by committee i.e. the establishment of *"RAP Expert Task Group"* during the year 2007 by FHWA. The work of this committee was to improve the national guidance in RAP. Up until mid- 2000s, agencies were using RAP up to a mark of 12%. A further need of research was felt due to rise in price of crude oil during Great Recession in late 2008.

4.0 Development of Mix Design Method for RAP and RAS Incorporated WMA:

There are numerous recycling materials available for use in flexible pavements in which most common commodities are Reclaimed Asphalt Pavement (RAP), Reclaimed Asphalt Shingles (RAS), Reclaimed Construction Aggregate (RCA), Oil Shale Ash wastes (OSA), Recycled Marble Aggregates (RMA) etc.

Further categorization of recycled material is based on where it is used in asphalt mix i.e. as a filler material and aggregate is shown in table: 2 below:

Table: 2 Recycled filler and aggregate materials.

Sr. No.	Recycled filler material	Recycled aggregate material
1	Waste tire rubber [Liu et al., 2017]	Reclaimed Asphalt Pavement (RAP) [Farooq et al., 2018]
2	Waste plastic bottles [Ahmadinia et al., 2011]	Reclaimed Construction Aggregate (RCA) [Shaopeng et al., 2013]
3	Recycled fine aggregates powder [Chen et al., 2011]	Roof Shingle Aggregate (RSA) [Kee et al.,1999]
4	Agricultural wastes such as rice husk ash [Al-Hdabi., 2016]	Recycled Marble Aggregate (RMA) [Nejad et al., 2013]
5	Jordanian oil shale fly ash [Radwan et al., 2013]	Electric Arc Furnace Slag (EAF) [Lastra-González et al., 2018]

The characteristics property of alternative aggregate to be examined are: specific weight (g/cm^3), flakiness index, Los Angeles coefficient, water absorption (24 hours in %), polished stone value (PSV), expansiveness and leaching test etc.

In order to spread the acceptance of RAP and RAS among public agencies and contractors, researchers and engineers need to evolve a fruitful mix design process with simple performance test. Volumetric analysis of RAP (and RAS) material have problems because the specific gravity of RAP (and RAS) material are difficult to evaluate due to the adhered aged (oxidized) binder over the aggregates. Now, there are two methods of using RAP (and RAS) into asphalt mixes. Either to use extracted binder from RAP and recycled aggregates (after binder extraction) separately or direct use of RAP (and RAS) for preparation of asphalt mix. The suitability of method is dependent on age of oxidized bitumen, type of bound or unbound layer etc. Feasible option is the direct use of RAP into the mix.

Another issue in the mix design is the upper limit of percentage RAP and RAS which can be incorporated in asphalt mixes without affecting its durability. Although the use of RAP in surface layer is banned in some countries but the main aim is to replace 100% RAP by virgin aggregate [Xu et al., 2014]. The task is how to replace by 100% virgin aggregate, it is difficult due to high level of stiffness in 100% recycled (oxidized) bitumen which will be resulted in long term distresses such as creep, fatigue and thermal cracking etc.

5.0 Rejuvenators:

During the service life of a flexible pavement, it is subjected to sun rays, traffic loading, rain and snow, these processes deteriorates the pavement and oxidize the bitumen which in turn reduces its flexibility and binder got stiff in nature. This process of stiffening of binder is called aging of binder. The aged binder has mixing issues with the virgin bitumen, this problem may be solved by incorporating softeners or rejuvenators [Yu et al., 2014] or some WMA additives which can work as rejuvenators along with reduction in production temperature. Although the cost of softeners/ rejuvenators is more the asphalt alone but they are needed to soft the oxidized binder.
Recently various studies have conducted to find the low cost and suitable rejuvenator for the reclaimed asphalt mixes, in this direction there are some rejuvenators like used/ waste mobile engine oil which is cost free and a waste product to utilize. A study evaluated that the optimum rejuvenator (used mobile engine oil) dosages for (RAP%: Virgin WMA%) 20:80, 30:70, 40:60, 50:50 and 60:40 RAP-WMA mixtures are 10%, 10–12.5%, 12.5–17.5%, 15–17.5% and, 17.5–20% by weight of bitumen respectively with respect to Marshall Stability, Tensile Strength Ratio, Indirect Tensile Strength and Unconfined Compressive Strength test criteria [Wu et al., 2013]. In a study, waste edible oil was used as rejuvenator with 20% RAP. The dosages of rejuvenator varied from 5 to 15% by weight of bitumen. Result of Marshal Stability criteria indicate; optimum quantity of edible oil is 10% [Jain et al., 2017].

6.0 RAP and RAS Incorporated WMA:

It is possible to use RAP in WMA without compromising the performance [Mallick et al., 2008]. In a study, RAP material was used in the surface course of asphalt mixes and replaced by more than 80%. It is concluded that performance wise (laboratory) RAP incorporated HMA and WMA mixes performed better or equivalent to control HMA mix. The study was conducted as per Spanish code and regulations and it was reported that there is need to revise the mix design performance parameters for recycled aggregates into asphalt mixes. Further by using fatty acid amide wax, HMA temperature got reduced by 20˚C [Lastra-González et al., 2018]. Up to 20% RAP is suggested to use in Dense Bituminous Macadam (DBM) and Bituminous Concrete (BC) [Kumar, 2014]. In a study, 20:80 RAP-WMA mix shows better mechanical properties, both with and without rejuvenator. Without rejuvenator, up to 20% RAP can be used to prepare RAP-WMA mix and with rejuvenator up to 60% RAP can be used to prepare RAP-WMA mix [Farooq et al., 2018]. Based on Marshall Stability criteria optimum RAP proportion found out to be 30% [Ahmed et al., 2015]**.** It is seen in some studies that premature fatigue and cracking occur in RAP pavement due to higher aged binder under heavy loading conditions [Shah et al., 2007]. In cold climates, the reason of low temperature cracking may be the unknown diffusion between aged binder and virgin binder [Huang et al., 2005].

In RAP incorporated WMA, the optimum quantity of RAP for chemical, water containing and organic additive was found to be 10%, 20% and 30% respectively [Oner et al., 2015]. In an another study virgin aggregate was replaced by 50 and 30% RAP, results are tabulated below:

Table 3: Optimum percentages of RAP [West et al., 2013]

Sr.No.	**Percentage of RAP**	**Comments**
1	50% RAP	Performed well in wide variety of climate and traffic conditions

2	30% RAP	May use for asphalt overlays. Have shown equivalent performance to virgin asphalt mix.

Additional comments from NCAT's pavement test track test conducted by NCAT:

- Use of softer grade/ virgin binder quantity may reduce cracking and raveling.
- Stiffer mixes by incorporation of RAP resulted in lower tensile strains under heavy traffic loads.

The use of RAS from manufactured waste (MWAS) was started in University of Nevada, Reno in the mid- 1980. From this study it was found that increased amount of RAS increases the stiffness of the asphalt mix whereas it also contributed in increased tensile strength. The increased stiffness of mix may be compensated by use of more virgin binder or rejuvenator. The final conclusion from this study was that 20% incorporation of RAS is optimum for acceptable performance of mix [Farooq et al., 2018]. Another study with RAS was conducted on two mix gradation: dense- graded and stone- matrix asphalt(SMA). The research showed that for dense graded max amount of RAS is 5% whereas for SMA it is 10%. Incorporation of RAS can improve compactibility of mix. manufactured waste (MWAS) could improve low temperature performance (true for limited extent of PCAS). Conclusion of this study was reported by Minnesota Department of Transportation for use up to 5% RAS in asphalt mixes [New Comb et al, 1993]. In an another study, rutting performance of HMA and WMA found to be depended on percentage of RAP and type of WMA additive. Following asphalt mixes have shown better performance: (a) 30% RAP incorporated Evotherm-WMA, (b) 15% RAP incorporated Rediset WMA, (c) 15% RAP incorporated Latex foamed WMA, (d) 30% RAP incorporated Astec Double Barrel Green system foamed WMA. The fracture temperature determined from Thermal Stress Restrained Specimen Test (TSRST) was cooler on addition of WMA additives which indicates the improved flexibility of asphalt binder. On addition of antistrip additives moisture resistance of WMA is improved in comparison to HMA. Increase in RAP content lead to decreased fracture resistance i.e. fracture at warmer temperature whereas rutting resistance have increased [Louay et al., 2015].

In the United States at present approximately 95% RAP is recycled into HMA and WMA and rest 5% is used in Cold Mix Technology as base course and in shoulders as filling material. Less than 0.2% of RAP goes into landfill areas annually [Hansen and Copeland, 2015]. There are some probable concerns related to increased level of emissions other than Green House Gas (GHG) and emission of addition harmful gases due to high percentage of RAP and RAS recycling. In a study 15% RAP and 5% RAS have been used with HMA and WMA. The stack tests reported reductions in CO_2, CO and NO_x. Whereas, O_2 remained at same level and SO_2 have increased although well below the allowable limits [Middleton and Forfylow, 2009].

The computer program Pavement Life- cycle Assessment Tool for Environmental and Economic Effects (PaLATE) calculate the energy consumed in a construction operation [Horvath, 2003]. The energy consumed output from PaLATE is based on the inputs from Economic Input- Output Life Cycle Assessment (EIO-LCA) model [Green Design Institute, 2015]. Based on an analysis with PaLATE software by use of RAP (15 to 40%), the energy saving found to be in the range of 5 to 15% [Robinette and Epps, 2010]. Further there are some concerns related to recycling are listed below:

- Production of fines in the mix.
- Stiffness in the mix due to aged binder.
- Need of rejuvenator (sometime costly).
- High level of emissions in processing of RAP material.
- Optimum % of RAP and requirement of appropriate mix design method for it.

7.0 CONCLUSION:

The use of reclaimed materials less than or up to 70% is found satisfactory. A positive motivation found towards use of RAP in base layer of flexible pavement. Although recent studies showed that, RAP can be successfully used in surface layer too and gave satisfactory performance. RAP incorporated asphalt mixes has stiffed binder which may cause premature cracking, this problem can be solved by using softeners and WMA additives which works as softeners and results are satisfactory. The use of RAP incorporated WMA technology also gave good performance results and as per some studies RAP RAP proportion up to 20% is optimum based on Marshall Stability with WMA additive “Evotherm”. Future of RAP incorporated WMA is focused at 100% recycling of RAP.

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