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DEVELOPMENT OF SUSTAINABLE STONE MATRIX ASHPHALT MIXTURES UTILIZING STEEL SLAG AND WASTE PLASTIC: A Review

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Abstract - *A Stone Matrix Asphalt (SMA) compositions have changed greatly over time, and recent research has produced some encouraging findings. As a result, the use of SMA mixtures in the production of pavement increased in the paving industries. SMA mixes do, however, provide some difficulties or drawbacks that call for thorough comprehension. The review paper's objective is to outline some of the problems with SMA combinations and potential solutions. It is shown that the researchers are addressing a number of issues (such as aggregate gradation, stone-on-stone contact, drain down, and stabilising chemicals) linked to SMA mixtures. Based on their expertise, geographic location, climatic circumstances, and access to manufacturing facilities, numerous agencies have proposed their own aggregate gradation, and they are doing an excellent job. Stone-on-stone contact is only possible with the right aggregate gradation, and if it is not met, performance will suffer. Steel slag (SS) is an excellent mechanically and morphologically rich aggregate. However, the main issues with using steel slag are its high water absorption rate and subsequent volume expansion. Since it affects the performance of the entire combination, drain down is a major concern in SMA mixtures. Researchers have therefore highlighted how important it is to stop the same. In order to examine the drain down, several researchers used the National Cooperative Highway Research Program (NCHRP No. 424) protocol and ASTM D6390. They came to the conclusion that the drain down should be less than 0.3%. (by weight of mixture). Additionally, to lessen the drain, researchers are experimenting with various stabilising agents. Particularly beneficial stabilising agents include fibres and polymers. Recently, appropriate waste and recycling goods have been used as stabilising agents to lessen environmental contamination and drain down.*

Key Words: Stone Matrix Asphalt, economical, abration, mineralogical, steel slag, Rutting, Reduction of drain down

1.INTRODUCTION

SMA is a mix design that was created in Europe for incredibly lasting wearing courses. When used over a suitable pavement structure, they are resistant to rutting (permanent deformation) and tyre wear from studded tyres. The enthusiastic endorsement of the participants in the 1990 European Asphalt Study Tour organised by AASHTO, FHWA, the National Asphalt Pavement Association, the Asphalt Institute, and TRB generated interest in the usage of SMA in the United States. The initial strategy in the United States was to replicate SMA mixtures created in Europe using resources, machinery, and knowledge from the domestic asphalt sector. In the United States, SMA usage has continuously increased since 1991. SMA is a gap-graded mix made up of two components: a mortar with a high binder content and a skeleton of coarse aggregate with a high concentration. Stone-on-stone contact from the coarse aggregate skeleton gives the mixture strength, and the mortar's high binder component adds longevity. Fine aggregate, mineral filler, asphalt binder, and a stabilising agent are the typical ingredients in mortar. The asphalt binder is kept in the mixture during the high temperatures of production and application thanks to this stabilising addition. It is essential that the mixture be developed and installed with a robust coarse aggregate skeleton since the strength of SMA significantly depends on the stone-on-stone aggregate skeleton.

The coarse aggregate skeleton stone section of SMA provides a stone on stone contact to reduce rutting and provide skid resistance, according to its design philosophy. To prevent the drain off of the binder and to provide the mix longevity, there is enough specialist mortar (the Matrix component) holding the mixture together. In its meeting on April 22, 2006, the Flexible Pavement Committee (FPC) of the Indian Roads Congress (IRC) resolved that a specification for stone

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matrix asphalt suitable for Indian circumstances must be prepared. Dr. Sunil Bose provided suggestions for the first draught of the standard, which was created by Prof. P. S. Kendal.

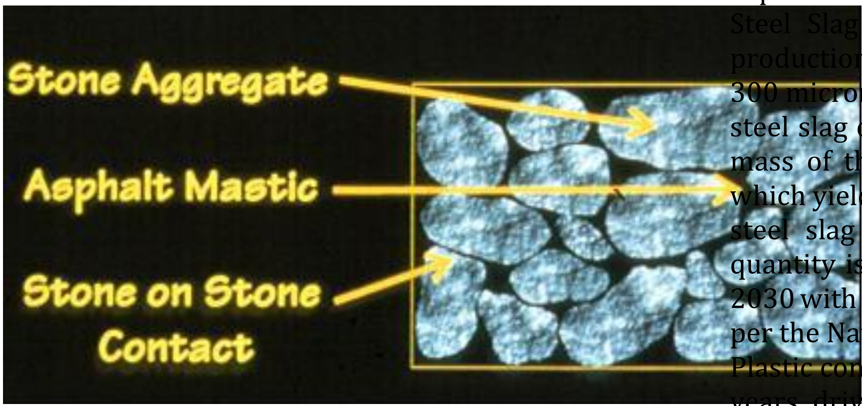

Fig.1-Components of SMA Mix

The Philosophy of SMA - Concept

The philosophy of the SMA - concept can be summarized briefly as follows:

- Strong proportion of crushed premium aggregates, excellent particle interlock, and great wear resistance provide high stability to permanent deformation and wear resistance.
- A very high bitumen content and a void-free mortar that fills the gaps in the stone skeleton and holds it together give structures longevity and resistance to premature cracking and ravelling. High quality and amount of bitumen are prerequisites for a long useful service life.
- The homogeneity (i.e., lack of binder drainage) of the mix during production, transportation, and laying is guaranteed by stabilising additives. They additionally increase steadiness.

Advantages of stone mix asphalt over conventional mixes

Conventional bituminous pavements are less resilient, long-lasting, and strong than SMA. We might conclude that SMA is superior to many traditional mixes for a number of reasons. In comparison to standard alternative pavement surfaces, SMA offers superior resistance to rutting caused by slow, heavy, and large volume traffic, resistance to deformation at high pavement temperatures, improved skid resistance, and reduced noise. SMA also boosts durability, decreases permeability, and exhibits enhanced resistance to the impacts of fatigue and breaking at low temperatures. Brown and Manglorkar (1993) claim that SMA exhibits good low temperature qualities as well as good resistance to plastic deformation under heavy traffic loads and high tyre pressures. Additionally, SMA has a rough texture that provides strong friction qualities once the traffic removes the upper surface film of the binder. SMA costs 20–25 percent more than traditional pavements, however they are justifiable due to the longer lifespan of the pavements. SMA has proven to be superior to HMA mixtures due to all these benefits.

Steel Slag is obtained as a waste product during production of steel .Particle size varies from 80 mm to 300 microns. According to Indian Mineral Book 2018, steel slag output is approximately 20-30 per cent by mass of the crude steel production in the country, which yields around a total 18.5 million tonne of solid steel slag production annually in the country,this quantity is slated to increase to 30 million tonne by 2030 with a likely increase in the production of steel as per the National Steel Policy 2017.

Plastic consumption has quadrupled over the past 30 years, driven by growth in emerging markets. Global plastics production doubled from 2000 to 2019 to reach 460 million tonnes. Plastics account for 3.4% of global greenhouse gas emissions.

Global plastic waste generation more than doubled from 2000 to 2019 to 353 million tonnes. Nearly two-thirds of plastic waste comes from plastics with lifetimes of under five years, with 40% coming from packaging, 12% from consumer goods and 11% from clothing and textiles.

1.3 OBJECTIVES AND SCOPES

- To prepare a mix design for Stone Matrix Asphalt using steel slag and waste plastic
- To enhance the properties of SMA by introduction of waste plastic to reduce draining down condition.
- To evaluate the abrasion properties of the Stone Matrix Asphalt mix
- To examine the moisture damage control efficiency of the SMA

2 LITERATURE REVIEW

Kumar et al (2009) Road transport in India is carried by a vast network of about 3.3 million km of roads, making it the third largest road network in the world. National highways form the primary network of roads and serve different routes across the country with a total length of about 58,000 km. The whole road network is seriously capacity-constrained and deficient, which has adversely affected traffic movement. The position has further worsened because of the phenomenal vehicle population growth from 0.3 million in 1951 to about 50 million in 2000, together with a substantial increase in axle loads. In India 98%

of the pavements are of the flexible type. Flexible-type pavements provide a resilient, waterproof, load-distributing medium that protects the base course from the detrimental effect of water and the abrasive action of traffic. Bituminous pavements are subjected to maintenance because of wear, weathering, and deterioration from aging. Flexibility of bituminous pavement permits slight adjustments in the pavement structure, resulting from consolidation of base course or effect of load, without detrimental effect.

IRC: SP: 79(2008) In the sixties and early seventies, studded tires were used in Germany during wintertime. The wear of asphalt surface courses under the spikes was extreme. Research and investigations on the performance of surface courses of Asphalt Concrete (AC) verified that wear and rutting by studded tires was increased by:

- high air void content of the surface course
- low bitumen content
- Inadequate quality and quantity of aggregates

In the end of the sixties, these results were the starting point for several large companies of the asphalt paving industry to develop specific mixes which were published under different proprietary names. Later, all these mixes were standardized and called Stone Mastic Asphalt or Stone Matrix Asphalt as in India.

Sehgal and Abele (2011) In 1975, the use of studded tires was banned. In the following time surface courses with AC and prototype SMA mixes showed a different performance of heavily trafficked highways: AC with high bitumen content was disposed to permanent deformation, whereas AC with low bitumen content was disposed to aging and 15 preliminary cracking. However under equal conditions both types of distress were not observed with SMA - surface courses. Practical experiences and observations proved that SMA is a better mix than AC. Years after the successful application of the Stone Mastic Asphalt principle in Germany; other European countries are using this philosophy also for heavy traffic roads. Now, many countries worldwide have taken over the philosophy of the Stone Matrix Asphalt.

Druschner and Schafer (2005) Over 30 years experience has shown that wearing courses made with SMA have an above average useful lifetime due to their special design; based on the one hand, on a high amount of chippings and on the other, high binder and mortar content. The first designs used a binder content of over 7 % by weight using asbestos fiber or rubber powder as stabilizing additives. The type and characteristics of the stabilizing additives were of special importance when using this high amount of binder. In the years following, the original design underwent a series of changes for technical, economical and ecological reasons. Today, for example, other stabilizing additives such as cellulose and mineral fibers, thermoplastics and silica are used. With some of these additives, the high binder content could not be added into the mixture without damaging it, i.e. some wearing courses with lower binder contents and less coarse aggregate and mineral content were produced. These wearing courses were, however, closer in character to Asphalt Concrete.

Bradley et.al. (2004) studied Utilization of waste fibers in stone matrix asphalt mixtures. They used carpet, tire and polyester fibers to improve the strength and stability of mixture compared to cellulose fiber. They found no difference in moisture susceptibility and permanent deformation in SMA Mix containing waste fibers as compared to SMA Mix containing cellulose or mineral fiber.

Punith V.S., Sridhar R., Bose Sunil, Kumar K.K., Veeraragavan A (2004) did a comparative study of SMA with asphalt concrete mix utilizing reclaimed polythene in the form of LDPE carry bags as stabilizing agent (3 mm size and 0.4%) .The test results indicated that the mix properties of both SMA and AC mixture are getting enhanced by the addition of reclaimed polythene as stabilizer showing better rut resistance, resistance to moisture damage, rutting, creep and aging.

Shaopeng Wu et al(2007) used slag after 3 year of ageing with PG76-22 modified binder, lime stone filler, short chopped polyester fiber (3%) for the SMA mix in Marshall method and found it to be suitable for use.

Chui-Te Chiu, Li-Cheng Lu(2007) used asphalt rubber (AR),produced by blending ground tire rubber (GTR) (i) 30% of a coarse GTR with a maximum size of #20 sieve and (ii)20% of a fine with a maximum size of #30 sieve with an asphalt, as a binder for SMA and found AR-SMA mixtures were not significantly different from conventional SMA in terms of moisture susceptibility and showed better rutting resistance than that of conventional dense graded mixture.

Yongjie Xue, Haobo Hou, Shujing Zhu, Jin Zha (2008) used municipal solid waste incinerator (MSWI) fly ash as a partial replacement of fine aggregate or mineral filler and BOF Slag as part of coarse aggregate with polyester fiber of 6.35 mm in length obtained from recycled raw materials, PG76-22 binder in the SMA mix and performed Marshall and super pave method of design and found it's suitability for use in the SMA mix.

Kamaraj C., G. Kumar, G. Sharma, P.K. Jain and K.V. Babu (2004) carried laboratory study by using natural rubber powder with 80/100 bitumen in SMA by wet process and also as dense graded bituminous mix with cellulose fiber and stone dust and lime stone as filler and found its suitability as SMA mix through various tests.

Bindu, C. S., and K. S. Beena. (2010) used waste plastic as a stabilizing additive in Stone Mastic Asphalt, the Marshall Stability value of stabilized SMA was found to be 17kN, which is higher than the prescribed value of 6.2 kN and the percentage increase in stability value has been found to be 64% as compared to the conventional mix

Shiva Kumar, G., Shankar, A.U.R., Ravi Teja, B.V.S (2019) conducted an evaluation of SMA Mixtures Made with Polymer-Modified Bitumen and Stabilizing Additives, draindown, workability, and mechanical properties were found to be statistically significant in relation to fiber type and content. Further, addition of natural and pelletized fibers controls binder draindown compared to polymer-modified SMA mixtures.

Marco Pasetto, Nicola Baldo (2010) The studied EAF slags have shown physical–mechanical characteristics substantially equivalent to those of natural stone aggregates usually used in transportation infrastructure, full chemical compatibility with the hydrocarbon binders used in road pavements and no hazardous leaching behaviour.

Washington State Department of Transportation (WSDOT, 2000) has mentioned in the tech notes on SMA that as per National Asphalt Paving Association (NAPA), SMA is a tough, stable, rut-resistant mixture that relies on aggregate to aggregate contact to provide strength and a rich mortar binder to provide durability. These objectives are usually achieved with a gap graded aggregate coupled with fiber or polymer modified, and high asphalt content matrix. SMA mixture is composed of mineral aggregates, mineral filler, and asphalt binder and stabilizing additives. SMA is designed to maximize rutting resistance and durability. Mineral aggregates when bound with asphalt mortar forms a stone on stone contact framework to impart strength and toughness to the structure. Mineral filler plays an important role in the properties of SMA mixture in terms of air voids, voids in mineral aggregate and optimum binder content in the mix. Stabilizing additives such as polymers and fibers etc. are added to the mixture to reduce drain down of the binder material during the high temperature of production and placement. SMA meets the following demands upon an asphalt pavement:

- High wearing resistance-SMA has low air voids, which make the mix practically impermeable and provides satisfactory aging resistance, moisture resistance and durability.
- High adhesive capacity between aggregates and the bitumen with the increase in the amount of filler, cellulose fibers are added as stabilizer. The purpose of adding fibers is to absorb the binder, thicken the bituminous film and improve the adhesion.
- A mix with no tendency to separate- an efficient stabilization of the mastic in order to prevent its segregation from the course particles.
- Reduced water spray- because of its higher texture depth there is less water spray and at night there is glare reflected from the road surface and better visibility of road markings.
- Lower traffic noise- SMA road surface generally offer lower level of road noise due to texture properties.

3.0 MATERIALS AND METHODOLOGY

3.1 General

This chapter discusses the methodology which is to be adopted and the materials used in the preparation of Stone Matrix Asphalt (SMA) with and without banana fiber specimens for the Marshall Stability Test, Drain down Test, Indirect Tensile Strength Test and Rutting Test. Details of SMA with and without banana fiber mix design, preparation of specimens at different binder and fiber content and specimen testing have been discussed in this chapter.

3.2 Research Plan

Various tests were conducted to determine the physical properties of Bitumen and the coarse aggregate. Penetration test, softening point test, Flash and Fire Point test and Ductility test were conducted to know the physical properties of Bitumen while Abrasion test, crushing test, Shape test, Specific gravity test and Impact test were conducted on the aggregates to know its physical properties. Further Mix design, preparation of samples and laboratory investigation tests are going to be carried out.

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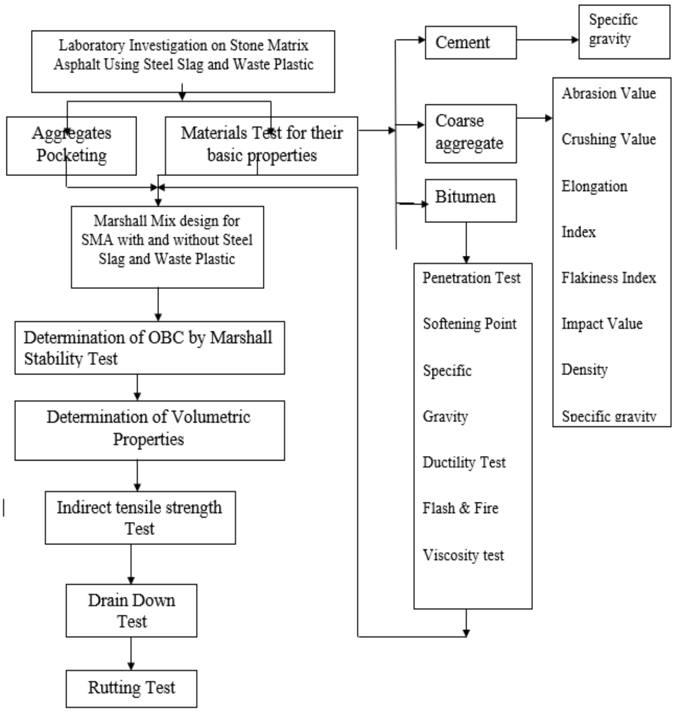

Materials

Bitumen

Plain bitumen of viscosity grade 30 will be used for preparation of specimens. The acceptable ranges are tabulated

Table-1 Physical properties of Bitumen

Sl. No	Tests	Range	As Per
1	Penetration Test (dm)	60-70	IS 1203-1978
2	Ductility Test (cm)	75 minimum	IS 1208-1978
3	Softening point (°C)	45-55	IS1205-1978
4	Flash point (°C)	175 minimum	IS 1209-1978
5	Fire point (°C)	175 minimum	IS 1209-1978

Aggregates

Coarse Aggregate: The coarse aggregates consisted of crushed granite rock retained on 2.36 mm sieve. They were clean, hard, durable, of cubical shape and free from dust and soft organic and other deleterious substances. The aggregates satisfy the physical requirements given in Table **Fine Aggregate:** Fine aggregates (passing 2.36mm sieve and retained on 0.075 mm sieve) consisted of 100 percent crushed sand resulting from crushing operations of granite rock. The fine aggregate were clean, hard, durable, of fairly cubical shape, and free from soft pieces, organic or other deleterious substances.

Table-2 Physical Properties of Coarse Aggregates

Sl. No.	Tests	IS-Codes	MoRT&H Specifications (2009)
1	Specific gravity	IS-2386 Part III	-
2	Crushing Value	IS-2386 Part IV	-
3	Abrasion Value	IS-2386 Part IV	Max 25%
4	Impact Value	IS-2386 Part IV	Max 24%
5	Water Absorption	IS-2386 Part III	2%
6	Combined Elongation and Flakiness Indices	IS-2386 Part I	Max 30%

Mineral filler: The filler material used in the study is granite stone dust and cement. Fly ash is not permitted as a filler material in SMA. As it creating difficulty in mixing when binder is added to the aggregates. Of the 8% (passing 0.075mm IS sieve) filler used, 6% is stone dust and 2% is cement. The filler was graded within the limits indicated in the Table.

Table-3 Grading Requirements of Mineral Filler

Mix Design Parameters	Requirements
Air Void Content, %	4.0
Bitumen Content, %	5.8 minimum
Voids in Mineral Aggregates (VMA), %	17 minimum
Voids in Coarse Aggregates mix (VCAMIX), %	Less than Voids in Coarse Aggregates in the Dry Rodded Condition (VCADRC)
Asphalt Drain down, % AASHTO T 305	0.3 maximum
Tensile Strength Ratio (TSR), % AASHTO T 283	80 minimum

3.3.3 Stone Matrix Asphalt Gradation

In the present investigation SMA samples are to be prepared by using 60/70 grade bitumen with and without banana fiber and to compare the properties of both SMA Mix. The 13mm SMA gradation i.e.; wearing courses with nominal layer thickness of 40 to 50mm is adopted. The SMA Mix requirements specified by the Ministry of Road Transport and Highways (MoRT&H, 2009) and Aggregate Composition of SMA (MoRT&H 2009) are tabulated in Table below.

Table-4 SMA Mix requirements (MoRT&H 2009)

IS Sieve (mm)	Cumulative % passing by weight of total aggregate
0.600	100
0.300	95-100
0.075	85-100

METHODOLOGY

A. Preparation of raw materials

o Collection of Waste P.E.T plastic from scrap center/ Municipal treatment units.

o Cleaning of plastic.

o Shredding and cutting into fine pieces.

o Collection of bitumen, stone aggregates and steel slag from the supplier.

B. Ingredient Testing and characterization of steel slag used

C. Following tests were carried out on ingredient materials before their use

1. Tests on Aggregates
   i. Sieve Analysis
   ii. Aggregate Impact Value
   iii. Aggregate Crushing Value
2. Tests on Bitumen
   i. Penetration Test
   ii. Softening Point Test
   iii. Ductility Test
3. Drain down test
4. Cantabro loss test
5. Moisture Control Test

Drain down

One of the major problems that incur in the SMA mixtures is drain down, which occurs at high temperature when asphalt liquefies and mastic materials separated from the mixture (Bocci and Prosperi, 2020; Brown and Mallick, 1994). So, it is important to limit the drain down to an acceptable level (Brown et al., 1997). In an SMA mixture, there is the certain verge of asphalt content at which the drain down is minimum, and once this verge exceeds then the drain down occurs. Brown and Mallick (1994) found that an increase in 1% asphalt content (i.e., 1% more than OBC) will increase the drain down by five folds. The drain down value evaluates the sensitivity of SMA mixture at elevated temperatures. Therefore, it is important to determine the drain down and appropriate measures must be taken to reduce the same. 3.1. Drain down tests In the past, the Schellenberg binder drain down test was developed to evaluate the drain down phenomenon. In this test, the drain down value greater than 0.3% is considered as unacceptable, equal to or less than 0.3% is acceptable, and lesser than 0.2% is exceptional. Stuart and Malmquist (1994) and Mogawer and Stuart (1995) evaluated the drain down of the SMA mixtures using four tests namely the Schellenberg binder drain down test, FHWA 2.36 mm sieve test, FHWA Open Graded

Friction Course (OGFC) drain down test and NCAT drain down test. They concluded that all four test procedures have few setbacks and have failed to measure the drain down accurately. Brown and Mallick (1995) developed the round-robin test method to measure the drain down phenomenon and this method is accurate, inexpensive, and simple. However, detailed evaluations were necessary to find a correlation between the laboratory and field drain down. Xie et al. (2003) conducted the drain down tests using 6.5 mm standard wire mesh and 2.36 mm wire mesh for the 4.75 mm NMAS mixes, and the results found that 2.36 mm wire mesh showed lesser drain down values. The AASHTO developed a test procedure to evaluate the drain down using uncompacted mixture. According to the specifications, the test uses a drain down basket made up of 6.3 mm sieve cloth and as seen in (Sarang et al., 2015). The acceptable drain down is less than 0.30% (AASHTO T305). The ASTM D6390 provided guidelines to determine the drain down phenomenon of the SMA mixtures for both laboratory and field samples. Currently, AASHTO and ASTM methods are generally followed to evaluate the drain down (Cooley and Brown, 2001; Devulapalli et al., 2019; Katla et al., 2020). The AASHTO and ASTM methods are better than the other test methods because they have addressed all the setbacks (accuracy, consistency, reliability and economical) and presented an accurate method. Based on the Indian conditions, IRC recommended ASTM D6390 specification to find the drain down and Eq. (4) is used to find the same (IRC SP 79-2008). Globally, researchers and practitioners following the AASHTO T305 and ASTM D6390 test methods to evaluate the drain down (DD, %) in SMA mixtures. DD ¼ 100 D ———————————— C B ———————————— A (4) where A is mass of the empty wire basket (kg), B is mass of wire basket with sample (kg), C is mass of the empty collecting plate (kg), D is mass of the collecting plate with drained material (kg).

3. CONCLUSIONS

- With recent curbs on stone quarrying in Karnataka and reduction in the availability of aggregates necessary for highway construction an alternative has to be made use of.
- Industrial wastes like steel slag along with waste plastic can be used to replace the stone aggregates.
- The non biodegradable property of waste plastic of which has been a menace to the environment can be used to our advantage in highway construction.
- The introduction of waste plastic reduces the draining down in SMA

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