浙江省交通运输科技成果推广目录申报表

一、成果概况

成果名称	高性能灌入式复合路面车辙处治技术
成果类型	○√技术　　○工艺　　○材料　　○产品
专业领域	道路工程
申报单位	金华市公路管理局
联系人及电话	邹晓勇；13958484735
推广应用起止时间	2020 年 1 月 ～ 2022 年 12 月
申报单位意见	我单位申请将上述成果列入《浙江省交通运输科技成果推广目录》，并承诺所有关于申请单位与成果的文件、证明、陈述均真实、准确。如有违背，我单位将承担由此产生的一切后果。 申报单位法人代表签字： 申报单位公章： 年　月　日
主管部门推荐意见	市交通运输局（委）或厅管厅属单位或省级有关单位意见 公　章： 年　月　日

二、成果简介（可另附页）

成果简介	本项目于 2020 年 1 月通过省交通运输厅鉴定，项目成果达到国际先进水平。 1. 成果原理：高性能灌入式复合路面技术是在 20%~30%的大空隙沥青路面中灌注专用灌浆材料形成的一种新型复合路面材料，该种复合材料通过沥青集料的嵌挤作用和灌浆材料的硬化共同形成强度，技术从结构的角度改变了路面的体系，将柔性体系转成半柔性体系，从根本上解决了沥青路面车辙产生的原因。 2.技术特点：研究成果突破了阻碍该技术推广应用的难题，具有的技术特点为：①施工便捷快速，专用灌浆料流动性好，无需振捣，灌满程度高；②强度增长快，施工结束两小时便可开放交通；③路用性能优异，具有超强的抗车辙性能；无收缩、不开裂；表面构造深度大，安全抗滑。 3.技术适用性：该技术特别适用于解决重载路段、长大坡路段、道路交叉口、公交站台、匝道、收费广场、BRT 以及疏港道路等车辙频发路段的病害难题，可以有效延长路面使用寿命，降低道路全寿命周期费用。
专利	1.201910315764.2；2019.04.19；发明专利；公开状态；本发明公开了一种复合路面结构，属于道路 工程养护领域。所述复合路面结构包括从下到上依次成型的路面承载基层、基层粘结密封层、缓冲层、碎石封层、复合路面层。该结构具备抗变形能力强、受力均匀、强度增长快的优点，缩短了路面的养护封闭交通时间，可以大幅提高路 面的使用寿命，减少路面周期养护成本。同时本发明还公开了一种复合路面结构及养护方法。 2.201910379482.9；2019.05.08；发明专利；公开状态；本发明涉及级配碎石灌入式半柔性复合路面混合料，包括如下质量分数的组

<table>
<tr><td></td><td>分：级配碎石 100 份；水 4-6 份；灌浆料 6-10 份；所述灌浆料包括 水泥、水性丙烯酸树脂、火山灰材料和水，所述罐浆料灌入上述级配碎石中。采用本发明的半柔性复合路面混合料在常温下即可施工，可有效的 解决沥青路面车辙病害问题，改善路面的耐久性 能；降低灌入式半柔性路面热拌施工对环境的污 染问题；提高灌入式复合路面的施工效率，降低生产成本。</td></tr>
<tr><td>软件著作权</td><td>/</td></tr>
<tr><td>标准规范</td><td>/</td></tr>
<tr><td>其它已取得的成果</td><td>发表两篇 EI 论文，分别为：《A Critical Appraisal on Pavement Performance of Early-Strength Irrigated Semi-flexible Pavement》、《Influences of Matrix Asphalt on Performance of Irrigated Semi-flexible Pavement》</td></tr>
</table>

三、有关指标（可另附页）

<table>
<tr><td>技术指标</td><td>
1. 建立了满足工作性能、力学性能和体积稳定性能的早强型灌浆料质量指标体系，具体见表 1。
表 1 早强型灌浆材料性能指标体系
<table>
<tr><th>性能</th><th>单位</th><th>要求</th><th>养护龄期</th></tr>
<tr><td rowspan="2">流动度</td><td rowspan="2">s</td><td>10~14</td><td>0h</td></tr>
<tr><td>10~16</td><td>0.5h</td></tr>
<tr><td>离析率</td><td>%</td><td>≤5</td><td>3h</td></tr>
<tr><td>泌水率</td><td>%</td><td>≤4</td><td>0.5h</td></tr>
<tr><td>初凝时间</td><td>min</td><td>≥45</td><td>-</td></tr>
<tr><td>终凝时间</td><td>min</td><td>≤120</td><td>-</td></tr>
<tr><td>抗压强度</td><td>MPa</td><td>≥10</td><td>3h</td></tr>
<tr><td>抗折强度</td><td>MPa</td><td>≥4.0</td><td>3h</td></tr>
<tr><td>体积变化率</td><td>%</td><td>-0.10~+0.36</td><td>60d</td></tr>
</table>
</td></tr>
</table>

	2.提出了适用于重载路段高性能灌入式复合路面的大空隙沥青混合料的适宜空隙率、适用沥青类型和集料类型。 具体为大空隙沥青混合料的适宜空隙率为15%~30%，SBS改性沥青和高黏改性沥青、玄武岩和石灰岩均能作为大空隙沥青混合料的胶结料和集料。 3.提出了不同重载情况下灌入式复合路面的适宜厚度及层位。具体为：对于水稳层上加铺两层结构时，在标准荷载情况下，灌入式复合路面的适宜厚度应不小于5cm；在超载50%和100%情况下，灌入式复合路面的适宜厚度应不小于7cm；对于水稳层上加铺一层结构时，在标准荷载情况下，灌入式复合路面的适宜厚度应不小于8cm；在超载50%和100%情况下，灌入式复合路面的适宜厚度应不小于10cm。同时，灌入式复合路面可适用于路面结构的中面层和上面层。 4.编制了《高性能灌入式复合路面施工应用指南》（初稿）。具体包括材料技术指标，复合路面混合料的设计与施工，以及施工质量控制与管理等，可以为灌入式复合路面的推广应用提供有力的技术支撑。
经济指标	项目成果已成功应用于重载路段车辙病害处置工程中铺筑路面近10万m2，经济指标计算如下： （1）社会效益：大空隙沥青混合料施工温度较热拌沥青混合料降低20℃左右，沥青用量减少约40%，施工过程节约能耗30%以上，减少 NOx、甲苯、二甲苯以及苯乙烯等有害气体排放量20%以上；同时凭借其优异的路用性能，减少了车辙病害的发生，保证行车的安全，减少了道路施工养护次数，减少施工对社会通行的影响。 （2）经济效益：在灌入式复合路面正常的服务周期内，传统养护技术需要养护6-9次，计算其3年养护寿命成本为90-135元/(m2*cm)，而灌入式复合路面的3年养护寿命成本约为25元/（m2*cm）左右，降低养护成本150%以上， 显著降低道路养护成本。

可采取的推广应用措施	该技术可以在新建工程改扩建工程及养护工程中进行推广应用。可采取的推广措施如下： （1）面向业主单位，针对重载超载严重、车辙病害一直未能得到有效解决、对灌入式复合路面技术迫切需求的地方县市，进积极向当地交通部门业主单位汇报推广该技术，并积极组织邀请业主单位参观现场样板工程，考察该技术的实体应用效果。 （2）面向设计单位，可以协助设计单位对拟施工路段病害进行调研分析，结合灌入式复合路面的技术特点，有针对性的提出病害处理有效、施工操作可行、造价成本可接受的路面结构设计方案。 （3）面向施工单位，结合该技术的施工特点和难点工作，对施工单位员工进行技术培训工作，培养一批该技术领域专业的施工队伍；同时对施工单位提供全过程、全方位技术服务和现场施工指导工作，确保该技术施工质量。 （4）面向国内同行，积极参加国内、省内和地方县市组织的技术推广交流会、现场交流会等会议，加强该技术的推广宣贯工作，增加国内同行对该技术的了解和认可。
申报单位及其推广能力简介	金华市公路管理局为本项目第一承担单位，负责本项目的组织实施与协调管理、成果总结等工作。 金华市公路管理局具有雄厚的人力、物力和基础建设等方面的配套条件，拥有 7 名正高、20 余名高工的科技人员队伍。近年筹集投入科研创新经费 1000 余万元，已完成和正在承担的省级科技项目 30 多项，近五年主持编制部行业标准和省级地方标准 8 项，是浙江省总工会和科技厅联合命名的“高技能人才创新工作室”，荣获浙江省公路学会科学技术奖、浙江省科学技术进步奖、中国公路学会科学技术奖 10 余项。 金华市公路管理局近年来先后完成或正在开展《隧道自发光应急逃

生系统研究》、《高 RAP 掺量泡沫温拌热再生技术在干线公路上的应用》、《橡胶沥青抗裂系统在老路改造工程中的应用研究》等 30 多项科研项目的研究与推广应用，具有从事科研项目研究与开发的技术实力。同时，金华市公路管理局负责全市公路建设与养护管理，具有大量工程样本，可满足本项目实施需要。

推广应用实例

2017 年 12 月开始采用灌入式复合路面技术在金华市金东区 G330 曹宅镇交叉口等项目养护工程中取得成功应用后，陆续在浙江、江苏、山东等省（市）采用了“高性能灌入式复合路面在重载路段车辙处治中的应用研究”课题的科研成果，施工面积将近 10 万 m^2。部分工程统计情况如下表 2 所示。

表 2　灌入式复合路面推广情况统计表

省、市	工程名称	工程量（m^2）	施工时间
浙江	金东区 G330 省道岭下朱交叉口	1000	2017.12
	S103 省道曹宅交叉口	1000	2017.12
	浦江杭金线郑家坞交叉口	1200	2018.1
	永康、兰溪 G330 省道交叉口	2800	2018.1
	金东区曹塘澧试验路	1800	2018.10
	杭州市余杭区 S207 省道养护工程	3520	2018.10
	金华金义快速路与正涵北街交叉口	1500	2018.11
	永康市花街东大道交叉口	1000	2019.1
	婺城西二环与长湖路交叉口	1000	2019.1
	长兴 G318 养护工程	4200	2019.8
	永武线养护工程	7236	2019.10
江苏	沿江高速太仓等主线收费站	6500	2018.7
	海门长江路等交叉口养护工程	3000	2018.9
	如东泰山路养护工程	1500	218.11
	海门沿江公路等交叉口养护工程	3350	2019.5

	沿江高速平望枢纽等养护工程	7400	2019.7
	扬州 G233 国道大中修工程	3136	2019.8
	S247 宁连公路养护工程	10715	2019.11
山东	临沂西外环养护工程	2000	2018.10
	临沂南外环养护工程	11538	2019.11
	潍坊新区长江西路交叉口	6160	2019.9
上海	南亭公路等交叉口	4820	2019.7

通过工程应用及跟踪调查结果，形成以下几点体会：

（1）采用了高性能灌入式复合路面技术后，有效的解决了重载交叉口路段的因车辙病害一年修多次的难题，显著降低了养护路段的周期性养护成本，经济效益显著，同时减少施工对社会的影响。

（2）通过两年多的使用情况来看，高性能灌入式复合路面的抗车辙效果显著，平整度、构造深度等各项检测指标良好，大大提高了养护路段的通行质量。

证明材料目录

鉴 定 意 见

受浙江省交通运输厅委托，浙江省公路与运输管理中心于2020年1月9日在杭州召开了“高性能灌入式复合路面在重载路段车辙处治中的应用研究”（项目编号2018H32）项目成果鉴定会。鉴定委员会（名单附后）听取了项目组的研究报告、科技查新报告、用户报告和财务审计报告，审阅了有关技术资料，经讨论，形成鉴定意见如下：

一、 提交鉴定的技术资料齐全、规范，符合鉴定要求。

二、 项目组通过查阅、检索国内外灌入式复合路面的研究现状，进行了灌入式复合路面用灌浆料的技术指标体系研究；大空隙沥青混合料的材料指标要求及配合比设计研究；灌入式复合路面的力学性能、路用性能及适宜层位结构研究；灌入式复合路面技术在养护工程中的应用研究等。取得的研究成果在依托工程的多个交叉口中得到了应用。

三、 项目研究的主要创新点为：

1、提出针对灌注式复合抗车辙路面的高性能专用灌浆材料的技术指标；

2、针对灌浆料的灌注可行性和灌入式复合路面的路用性能，提出大空隙沥青混合料的适宜空隙率、集料类型和沥青类型。

四、 项目预算总经费55万元，其中省财政科技经费补助20万元。经北京永恩力合会计师事务所有限公司审计（永恩审字【2019】G670295号），实际支出53.26万元，其中省财政经费支出20.00万元，省财政经费净结余零万元。经费使用基本合理。

鉴定委员会认为项目研究已完成了项目合同书规定的各项任务，研究成果总体达到国际先进水平。

建议进一步推广成果应用。

鉴定委员会主任委员：（签名）

2020年1月9日

文章编号：(2019) 0-0000-07

沥青和集料类型对灌入式半柔性路面路用性能的影响研究

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【摘 要】 基体沥青混合料的沥青类型、集料类型对灌入式半柔性路面的路用性能有重要的影响，分别以高黏沥青、SBS 改性沥青和 70#道路石油沥青、玄武岩集料和石灰岩集料成型灌入式半柔性路面 SFP-13 马歇尔试件，利用车辙试验、低温劈裂试验、浸水马歇尔试验来评价其高温性能、低温性能和抗水损害性能。试验结果表明：沥青类型对灌入式半柔性路面的动稳定度和浸水残留稳定度影响不大，主要影响低温性能和基体沥青混合料的性能，并且 70#道路石油沥青对低温抗裂性能降低幅度明显；集料类型对灌入式半柔性路面的路用性能影响较小，石灰岩集料对灌入式半柔性路面的低温抗裂性能和抗水损害性能相对于玄武岩集料有一定程度的提高；综合考虑路用性能和工程造价，建议 SBS 改性沥青和石灰岩集料可作为灌入式半柔性路面的沥青和集料。

【关键词】 沥青和集料类型；灌入式半柔性路面；路用性能
中图分类号： 文献标识码：A

Influences of Asphalt and Aggregate Types on Pavement Performance of Pouring Semi-flexible Pavement

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【Abstract】 Asphalt type and aggregate type of base asphalt mixture have important influence on the pavement performance of the pouring semi-flexible pavement. The Marshall specimens of the pouring semi-flexible pavement are formed with high-viscosity asphalt, SBS modified asphalt, 70# road petroleum asphalt and basalt aggregate and limestone aggregate respectively. The rutting test, low temperature beam bending test and immersion Marshall test are used to evaluate the performance of the pouring semi-flexible pavement. The test results show that the asphalt type has little effect on the dynamic stability and the residual stability of pouring semi-flexible pavement, mainly on the low temperature performance and the performance of base asphalt mixture. And the 70# road petroleum asphalt has a great reduction in the low temperature crack resistance of the pouring semi-flexible pavement. Aggregate type has little effect on pouring pavement performance of semi-flexible pavement. Compared with basalt aggregate, limestone aggregate can improve the low temperature crack resistance and water damage resistance of pouring semi-flexible pavement. Considering the pavement performance and engineering cost, it is suggested that SBS modified asphalt and limestone aggregate can be used as asphalt and aggregate for pouring semi-flexible pavement.

【Keywords】 Types of asphalt and aggregate; Pouring semi-flexible pavement; Pavement performance

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1 前 言

近年来，随着我国道路交通运输行业逐渐向重型化、大型化方向发展，加上交通量日益增大和汽车超载现象的增加，车辙病害已成为沥青路面的主要病害，如何有效解决路面车辙病害问题成为公路养护部门的一大难题。

灌入式半柔性路面被证实是一种有效解决沥青路面车辙病害的新技术，该技术是在大空隙沥青混合料中灌注水泥基灌浆料而形成的刚柔并济的复合型路面结构[1-2]。国内外对灌入式半柔性路面技术进行了一定程度的研究和应用[3-5]。研究结果表明，半柔性材料的强度主要受水泥浆体的强度影响，水泥基灌浆料的加入，可以显著提升马歇尔稳定度2.5~3.0倍，在基体沥青混合料空隙率为25%时，半柔性路面的各项综合路用性能效果最佳。目前的研究主要在考察灌入式半柔性路面的路用性能以及灌浆料对其性能的影响，对基体沥青材料的研究较少，而且当前的工程应用原材料主要是采用高性能改性沥青和玄武岩集料，工程造价高，不利于该技术的推广应用，考虑到灌入式半柔性路面的优异路用性能，是否可以在保证路用性能的同时，降低对原材料的性能要求，以降低工程造价。因此，本文分别考察三种沥青类型和两种集料类型对灌入式半柔性路面的路用性能影响规律，进而优选出适宜的沥青和集料类型，以指导现场施工。

2 试验材料准备

2.1 沥青

试验用沥青采用南通通沙沥青厂生产的70#道路石油沥青（PA）、SBS改性沥青（SBS）和高黏改性沥青（HV）。按规范[6]要求对三种沥青的各项基本性能指标进行测试，试验结果见表1。

表1 三种沥青基本性能指标测试结果

Table 1 Testing results of 13 basic performance indicators of asphalt

Test items	PA	SBS	HV
Penetration (25℃、100g、5s) /0.1mm	66.5	62.8	58.9
Ductility (5℃、5cm/min)/cm	5.1	32.1	38.4
Softening point /℃	47.4	82.2	93.6
Flash points/℃	330	315	309
Density（15℃）/g·cm^{-3}	1.026	1.027	1.027
Solubility（Trichloroethylene）/%	99.9	99.8	99.8
Dynamic Viscosity（60℃）/Pa.s	1582	14285	128920

2.2 集料

试验采用两种集料类型，分别为石灰岩（LS）和玄武岩（BS），1~3#料从粗到细的粒径规格为：10~15mm、5~10mm、0~5mm，矿粉均采用的是石灰岩矿粉，各集料和矿粉的基本性能指标如表2所示。

表2 集料的基本性能指标

Table 2 Basic Performance Indicators of Aggregates

Materials	1#（LS）	2#（LS）	3#（LS）	Mineral powder	1#（BS）	2#（BS）	3#（BS）
Apparent density/g·cm^{-3}	2.751	2.746	2.724	2.721	2.906	2.918	2.889
Gross Bulk Density/g·cm^{-3}	2.719	2.706	2.664	/	2.874	2.853	2.823

Water absorption/%	0.43	0.54	0.83	/	0.38	0.78	0.81

2.3 水泥基灌浆料

水泥基灌浆料为试验室自制早强型灌浆料，水泥基灌浆料的水和干粉的质量比例为0.3:1，其各项检测指标见表 3 所示。

表 3 水泥基灌浆料的各项指标检测结果

Table 3 Test results of various indexes of cement-based grouting material

Test items	Unit	Test result	Technical requirement	Age
Fluidity	s	13.1	10~14	-
		14.4	10~16	0.5h
Segregation Rate	%	1.2	≤5	3h
Volume Change Rate	%	0.2	-0.10~0.36	60d
Compressive Strength	MPa	10.3	≥10.0	3h
Flexural Strength	MPa	3.7	≥2.0	

3 试验方法及试件的制备

3.1 大空隙基体沥青混合料配合比设计

为了确保基体沥青混合料的设计空隙率为 25%，采用体积设计方法[7]，通过多次室内试验调整验证，最终确定石灰岩集料和玄武岩集料配置的基体沥青混合料 SFP-13 的配比见表 4 所示，所得到的两种集料类型配置基体沥青混合料的合成级配见图 1 所示。

表 4 两种集料类型的配合比设计结果

Table 4 Mix design results of two aggregate types

Aggregate type	1#	2#	3#	Mineral powder
LS	75	16	6	3
BS	81	11	5	3

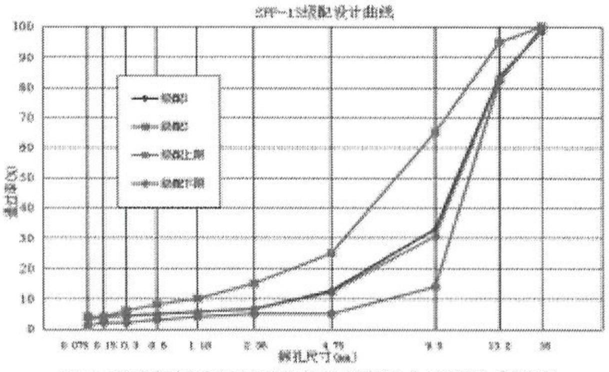

图 1 两种集料类型配置的基体沥青混合料级配曲线图

Fig.1 Gradation curve of base asphalt mixture with two aggregate types

3.2 基体沥青混合料性能验证

分别采用70#道路石油沥青、SBS改性沥青和高黏改性沥青制备上述的两种集料类型的沥青混合料，沥青油石比参考经验取值为3.0，使用马歇尔击实方法成型混合料试件，双面各击实50次；拌合温度为160℃，成型温度为150℃。测定试件毛体积密度、空隙率，最后进行马歇尔稳定度、流值，析漏和肯塔堡飞散试验，试验结果如表5所示。

表5 不同沥青和集料类型成型的马歇尔试件结果

Table 5 Marshall specimens formed with different asphalt and aggregate types

Asphalt and aggregate types	Gross bulk density/g·cm^{-3}	Voidage/%	Stability/KN	Stream value/0.1mm	Leakage rate/%	Flying loss rate of cantabro fort/%
PA+LS	1.905	25.7	2.4	48.5	0.32	46.2
SBS+LS	1.910	25.1	4.5	38.2	0.19	24.9
HV+LS	1.912	24.8	4.9	25.5	0.11	15.8
PA+BS	1.947	25.6	/	/	0.4	52.4
SBS+BS	1.952	25.0	4.3	35.6	0.22	29.8
HV+BS	1.950	25.3	5.0	29.2	0.16	19.4

从马歇尔试验结果可以看出，不同沥青和集料类型制备的马歇尔试件空隙率基本上都在25%左右，且石灰岩集料配置的试件空隙率与玄武岩的试件空隙率相当，说明采用体积法设计的的大空隙基体沥青混合料级配比较合理；从性能指标上看，在集料类型相同的情况下，沥青的各项性能越好，基体沥青混合料的马歇尔稳定度、流值、析漏率、肯塔堡飞散损失率越好，说明沥青黏度很大程度上改善了大空隙基体沥青混合料的性能；同样在相同沥青类型下，石灰岩集料的基体沥青混合料的各项性能指标比玄武岩好，主要是石灰岩集料和沥青的粘附性相对较好。但是，无论是石灰岩集料还是玄武岩集料，70#道路石油沥青制备的大空隙基体沥青混合料都无法满足马歇尔稳定度大于3.5KN的指标要求[8]，甚至，70#道路石油沥青和玄武岩集料都无法进行养护试验，初步可以确定，70#道路石油沥青不太适用25%空隙率的基体沥青混合料。

3.3 灌入式半柔性路面试件的制备

采用上述6种不同沥青和集料类型的混合料配合比设计结果，分别按照以下步骤制备灌入式半柔性路面试件：

（1）基体沥青混合料的成型：采用马歇尔击实成型法成型直径101.6mm×63.5mm圆柱体，采用碾压成型法成型试件尺寸为成型300mm×300mm×50mm车辙板试件，成型温度均为150℃。

（2）水泥基灌浆料的灌注：待基体沥青混合料试件冷却至常温后，按0.3的水灰比制备水泥基灌浆料，将制备好的水泥基灌浆材料灌入基体沥青混合料中，在浆体初凝之后约60min内将表面多余的浆体刮除掉，使表面露出构造纹理；

（3）养生处理：将表面处理后的试件放到标准养护室中进行养生（温度为20±2℃，湿度≥95%），28d后进行各项路用性能测试。

4 沥青和集料类型对灌入式半柔性路面性能的影响及结果分析

对灌入式半柔性路面混合料进行车辙试验、低温劈裂试验、浸水马歇尔试验[9-11]。根据试验结果分析不同沥青和集料类型对灌入式半柔性路面混合料的高温性能、低温性能、抗水损害性能之间的影响规律。

4.1 高温稳定性能

采用车辙试验来评价6种不同沥青和集料类型的灌入式半柔性路面混合料的高温稳定性，以动稳定度表征高温稳定性能。试验条件为：在60±1℃，0.7±0.05MPa条件下分别对灌入式半柔性路面混合料进行车辙试验，试验结果见图2。

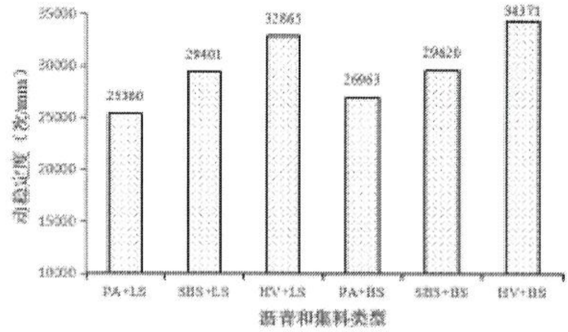

图 2 车辙试验结果

Fig. 2 Rutting test results

由动稳定度试验结果可以看出，同一种集料类型，随着沥青黏度的增长，灌入式半柔性路面的动稳定度指标呈现增长的趋势；同一种沥青类型，采用玄武岩集料的灌入式半柔性试件动稳定度要稍微高些，但动稳定度总体变化不大。而且不论是何种沥青和集料类型的灌入式半柔性路面，动稳定度均超过了 25000 次/mm，因水泥基灌浆料的加入，灌入式半柔性路面高温稳定性能都得到很大的提高，同时也说明了沥青和集料类型对 25%空隙率基体沥青混合料的灌入式半柔性路面的高温稳定性能影响不大。

4.2 低温稳定性能

混合料的低温抗裂性反映了混合料在低温及温度骤降条件下抵抗开裂破坏的能力，利用低温劈裂试验，比较不同沥青和集料类型的灌入式半柔性路面混合料的低温抗裂能力。试验条件为：采用温度为-10±0.5℃，加载速率采用 1mm/min，试验结果见表 6 所示。

表 6　低温劈裂试验结果

Table 6 Low temperature splitting test results

Asphalt and aggregate types	Splitting tensile strength R_T/MPa	Failure tensile dtrain $\mu\varepsilon_T$	Modulus of failure stiffness S_T/MPa
PA+LS	1.862	2171	1637
SBS+LS	2.109	2653	1307
HV+LS	2.207	2968	1218
PA+BS	1.746	1824	1765
SBS+BS	2.083	2381	1427
HV+BS	2.185	2747	1315

根据低温劈裂试验结果可知，在相同的集料情况下，随着沥青性能的提高，劈裂抗拉强度和破坏拉伸应变逐渐增大，劲度模量指标呈下降的趋势，说明灌入式半柔性路面的低温抗裂性能得到提高；以石灰岩集料为例，相比于 70#道路石油沥青，SBS 改性沥青和高黏改性沥青的灌入式半柔性路面的劈裂抗拉强度分别提高了 13.3%和 18.5%，破坏拉伸应变分别提高了 22.2%和 36.7%，破坏劲度模量分别降低了 20.2%和 25.6%，SBS 改性沥青和高黏改性沥青提高了灌入式半柔性路面的低温变形能力，改善了低温抗裂性能，主要是因为 SBS 改性沥青和高黏改性沥青低温变形能力较好，而 70#道路石油沥青在-10℃时偏向于脆性，抗变形能力较差，因此，考虑低温稳定性能，建议灌入式半柔性路面宜使用 SBS 改性沥青或高黏沥青。

相同沥青类型情况下，无论是 70#道路石油沥青，还是 SBS 改性沥青或高黏改性沥青，石灰岩集料制备的灌入式半柔性路面混合料的的相比于玄武岩集料的劈裂抗拉强度和破坏拉伸应变较大，劲度模量较小，说明石灰岩集料制备灌入式半柔性路面混合料的低温抗裂性能较好，这是由于石灰岩与沥青的粘附性较好，混合料沥青膜有效厚度更大，低温下具有更好的柔韧性。

4.3 水稳定性能

为了考察沥青和集料类型对灌入式半柔性路面混合料的抗水损害性能的影响，采用浸水马歇尔试验来研究其水稳定性能，试验条件为：分别将不同沥青和集料类型的灌入式半柔性马歇尔试件放入60℃水浴中养护0.5h和48h，取出后在25℃条件下进行马歇尔稳定度试验，并计算出马歇尔残留稳定度值见图3所示。

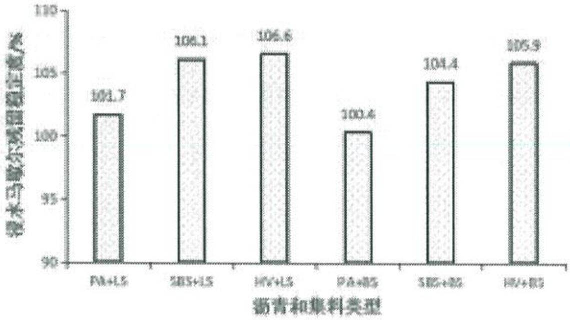

图3 马歇尔残留稳定度试验结果

Fig. 3 Marshall Residual Stability Test Results

从马歇尔残留稳定度结果可以看出，不管何种沥青和集料类型灌入式半柔性路面混合料，浸水残留稳定度均超过了100%，抗水损害性能均较好，这主要是因为60℃水浴养护48h后，水泥基灌浆料进一步水化反应使得强度得到进一步增长，以及灌浆料灌注后的半柔性路面试件较为密实所致。比较相同的集料类型，随着沥青性能的进一步提高，浸水残留稳定度呈增大的趋势，表明沥青的性能改善一定程度上可以提高灌入式半柔性路面的抗水损害性能；比较相同的沥青类型，石灰岩集料的灌入式半柔性路面混合料的浸水马歇尔残留稳定度值要优于玄武岩集料，主要由于石灰岩集料与沥青的粘附较好，改善了混合料的抗水损害性能。

5 结 论

通过对不同沥青和集料类型的灌入式半柔性路面的高温稳定性能，低温稳定性能和水稳性都能的影响规律研究，得出如下结论：

（1）沥青类型对灌入式半柔性路面的高温稳定性能和水稳定性能的影响较小，主要影响低温抗裂性能，基本上是高黏沥青最好，SBS改性沥青次之，70#道路石油沥青最差，考虑70#道路石油沥青对灌入式半柔性路面的低温破坏拉伸应变降低20%以上，破坏劲度模量提高20%以上，以及基体沥青混合料的稳定度、析漏率和飞散损失率较差，建议25%基体沥青混合料的灌入式半柔性路面宜采用高黏沥青或SBS改性沥青。

（2）集料类型对灌入式半柔性路面的高温性能影响不大，但是石灰岩集料对灌入式半柔性路面的低温抗裂性能和抗水损害性能、基体沥青混合料的稳定度、析漏率和飞散损失率相对于玄武岩集料有一定程度的提高，认为石灰岩集料可以作为灌入式半柔性路面的集料。

（3）综合考虑沥青类型和集料类型对灌入式半柔性路面的基体沥青混合料，路用性能，以及工程造价的影响，建议采用SBS改性沥青和石灰岩集料作为灌入式半柔性路面的沥青和集料。

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Author(s): Xingmin Liang, Xiaoyong Zou, Wenxiu Wu, Wenkun Wu

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A Critical Appraisal on Pavement Performance of Early-Strength Irrigated Semi-flexible Pavement

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Abstract: Early-strength irrigated semi-flexible pavement(EISFP) is a new type of composition pavement with the characteristics of both asphalt pavement and cement concrete pavement. It has the advantages of high strength in the beginning and fast strength growth. EISPF-13 Marshall specimens with voids of 20%, 25% and 30% of base asphalt mixture were formed respectively. Rutting test, low temperature trabecular bending test and immersion Marshall test were used to evaluate the high temperature performance, low temperature performance and water damage resistance of EISPF-13 maintained for 3 hours and 28 days. The test results show that the pavement performance of EISPF-13 with 3-hour maintenance has reached more than 70% of that which have been maintained for 28 days. Moreover, the dynamic stability, residual stability of EISPF-13 maintained for 3-hour are better than SMA-13 asphalt mixture. Low temperature crack resistance of EISPF-13 is slightly poor, but it can still meet the technical requirements.Considering its comprehensive road performance,it is suggested that EISPF can be used for the road maintenance with high traffic pressure,because it can withstand traffic loads after 3-hour maintenance.

Keywords: EISPF-13; SMA-13; Asphalt Mixture; Road Performance of Mixture

1. INTRODUCTION

Semi-flexible pavement(SFP) is a composition pavement which is formed by pouring cement-based grouting material into large void base asphalt mixture. This pavement structure not only retains the main performance of asphalt concrete pavement, but also has some performance of cement concrete pavement. Due to the interaction of aggregates and grouting of cement mortar, the resistance to load of SFP is improved. At the same time, the rutting resistance and water damage resistance of SFP are much better than those of the conventional asphalt asphalt concrete pavement,which greatly improves the service life of pavement and reduces the cost of periodic maintenance.

The earliest application of SFP began in 1954 at the runway of Cognac Airport in France. After that,Japan and other countries further improve the material and construction technology of SFP, and carried out a lot of engineering applications. The field test results show that projects of SFP have achieved good results[1-3]. A large number of studies also show that SFP has excellent road performance.

Jean Mayer[4] and others conducted a special investigation and study on the use of SFP in Copenhagen Airport. The investigation results show that SFP has the characteristics of small shrinkage, no cracks and no plastic flow damage. So it is very suitable for heavy load areas. Setyawan[5] believes that the strength of SFP is mainly affected by the strength of cement paste. And the strength of SFP is about 11% of that of cement paste. In addition, the compressive strength of SFP is also affected by asphalt properties. The compressive strength of SFP with soft asphalt is lower than that with hard asphalt, but the hardness of aggregate and the void fraction of asphalt mixture matrix are still the main factors affecting the compressive strength. Hao Peiwen[6,7,8] and others used various test methods to evaluate the high temperature stability, low temperature crack resistance, fatigue performance, water stability and oil corrosion resistance of SFP. The results show that SFP has excellent high temperature stability, fatigue resistance and oil corrosion resistance, and good water stability and low temperature stability when it was cured for 7 days.

A large number of experimental studies have shown that SFP has excellent pavement performance, and has been verified by a large number of engineering applications. But at present, the strength of SFP increases slowly and it's early strength is low. It takes at least 7 days, or even longer, from construction and maintenance to open traffic.It is difficult to meet the requirements of rapid maintenance of heavy and high traffic pressure sections. Therefore, the purpose of this paper is to develop the EISFP. Various test methods were used to evaluate its high temperature performance, low temperature performance and water damage resistance when it was cured for 3 hours and 28 days.And compared with the performance of SMA-13 asphalt mixture.it also verifies whether the EISFP is suitable for the maintenance and construction of the fast open traffic in heavy traffic section.

2.MATERIALS AND METHODS

2.1Materials

The materials used in this paper are asphalt binder, aggregate and cement-based grouting material.

2.1.1 Asphalt cement

The asphalt is SBS modified asphalt produced in Jiangsu Province, China. The test indexes of the asphalt are shown in Table 1, which can meet the requirements of the specification.

TABLE 1 Test results of various indexes of SBS modified asphalt

Properties	Requirements	Test result
Penetration (25℃、100g、5s) /0.1mm	30~60	46.5
Penetration index (PI)	Actual record	0.3
Ductility (15℃、5cm/min)/cm	≥30	34.3
Softening point (TR&B) /℃	≥60	85
Dynamic viscosity 135 ℃ Pa.s	≤3	1.4
Density (15℃) /(g/cm3)	Actual record	1.030
Solubility (trichloroethylene) / (%)	≥99	99.5
PG grade	Actual record	PG70-22

2.1.2 Aggregate

The aggregate in the test is basalt aggregate produced in Anhui Province. The size of 1# to 3 #

aggregate are 10-15mm, 5-10mm and 0-5mm. Limestone powder is ore powder. The basic performance of each grade aggregate and ore powder are shown in Table 2.

TABLE 2 Basic Performance Index of Aggregate

Material	1#	2#	3#	Ore powder
Apparent density（g/cm^3）	2.857	2.871	2.883	2.704
Bulk density（g/cm^3）	2.831	2.821	2.823	/
Water absorption（%）	0.32	0.62	0.74	/

2.1.3 Cement-based grouting

Dry powder of cement-based grouting material was self-made in laboratory. Water cement ratio of grouting material is 0.3. The performance of grouting material are tested as shown in Table 3.

TABLE 3 Test results of various indexes of cement-based grouting material

Test Item	Unit	Test result	Requirement	Age
Fluidity	s	11.7	10~16	0.5h
Segregation rate	%	1.1	≤5	3h
Volume change rate	%	0.14	-0.10~0.36	60d
Compressive strength	MPa	14.7	≥10.0	3h
Flexural strength	MPa	4.2	≥2.0	3h

2.2 Sample preparation of EISFP-13

2.2.1 Preparation of Matrix Asphalt Mixture

Ratio of matrix asphalt mixture was designed by Volume Design Method. The gradations of matrix asphalt mixture with voidage of 20%, 25% and 30% are shown in Table 4.

TABLE 4 Gradation of Three Matrix Asphalt Mixtures with Different Voids

Graded voidage	Passing rate of the following sieve（%）									
	16.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
20%	100.0	92.1	44.2	16.9	9.1	6.1	5.5	4.8	3.8	3.5
25%	100.0	87.1	31.2	11.3	8.3	5.8	5.4	4.6	3.7	3.3
30%	100.0	82.9	26.2	8.3	6.3	5.3	5.3	4.1	3.7	3.3

Standard Marshall specimens (101.6 mm×63.5 mm cylinder diameter) and rutting plate specimens

(300 mm ×300 mm ×50 mm) were formed by Marshall compaction method and wheel rolling method respectively with different voids.The ratio of asphalt is 3.0, the mixing temperature of mixture is 160 ℃, and the forming temperature is 150℃.Gross volume density, voidage, Marshall stability,and other indicators of specimens were tested as shown in Table 5.There is little difference between the measured and designed voidage, which indicates that the volume design method is more reasonable.

TABLE 5 Test results of asphalt mixtures with different voids

Designed voidage	Measured voidage (%)	Gross bulk density (g/cm3)	Stability (KN)	Flow value (0.1mm)	Lealage rate (%)	Flying loss of Cantabro (%)	Dynamic stability (times/mm)
20%	20.7	1.947	5.8	26.1	0.19	17.8	1681
25%	25.2	1.930	5.1	31.7	0.25	23.5	1347
30%	29.9	1.918	4.0	35.9	0.31	29.1	961

2.2.2 Preparation of test pieces for EISFP-13

The preparation of EISFP-13 specimens mainly includes the following three steps:

(1) Seal the bottom and periphery of Marshall specimens and rutting plate specimens of base asphalt mixture with 20%, 25% and 30% voids with tape. Then, the grouting material is prepared according to water cement ratio of grouting material is 0.3, and pouring the grouting material into the base asphalt mixture.

(2) Let the grouting material flow into the base asphalt mixture by itself. When the grouting material no longer seeps down, scraped off the superfluous slurry on the surface.

(3) Specimens filled with grouting material are maintained in standard maintenance room.The curing conditions are as follows: the temperature is 20±2℃ and the humidity is more than 95%. The specimens cured for 3 hours and 28 days are taken out for testing,respectively.

2.3 Methods

2.3.1 Rutting test

Rutting test is often used to evaluate the high temperature stability of asphalt mixture. it reflect the ability of asphalt mixture to resist deformation at high temperature[9].Rutting tests were carried out on specimens of EISFP-13 maintained for 3 hours and 28 days and SMA-13 asphalt mixtures under the conditions of 60±1℃, 0.7±0.05MPa,respectively. The relationship curve between rutting deformation and time is obtained, and the dynamic stability index is calculated to evaluate its high temperature stability.

2.3.2 Low temperature trabecular bending test

Low temperature trabecular bending test can reflect the deformation resistance of the mixture at low temperature[10]. Cutting the rutting slab of EISFP-13 and SMA-13 into 250±2.0mm in length, 30±2.0mm in width and 35±2.0mm in height. Under the conditions of temperature of -10 ± 0.5 C and loading rate of 1 mm/min,low temperature trabecular bending tests were carried out. The flexural strength, maximum flexural strain and modulus of flexural stiffness were calculated to evaluate its low temperature performance.

2.3.3 Water-Immersed Marshall Test

Water-immersed Marshall test can reflect the ability of mixture to resist water damage in the process of high temperature water action. The test was carried out on the specimens of EISFP-13 and SMA-13 asphalt mixture at 25℃. The curing condition of the sample is as follows: All kinds of EISFP-13 Marshall specimens and SMA-13 asphalt mixture specimens were maintained in water bath at 60℃ for 0.5 hours and 48 hours. Then Marshall tests were carried out to calculate the residual stability to evaluate it's water stability.

3.RESULTS AND DISCUSSION

Rutting test, low temperature trabecular bending test, and immersed Marshall test were carried out on EISFP-13 specimens and SMA-13 asphalt mixture to evaluate their high temperature performance, low temperature performance and water damage resistance when it was cured for 3 hours and 28 days.

3.1 High Temperature Stability of EISFP

Rutting tests were carried out on EISFP-13 specimens and SMA-13 asphalt mixture to obtain dynamic stability as shown in Figure 1.

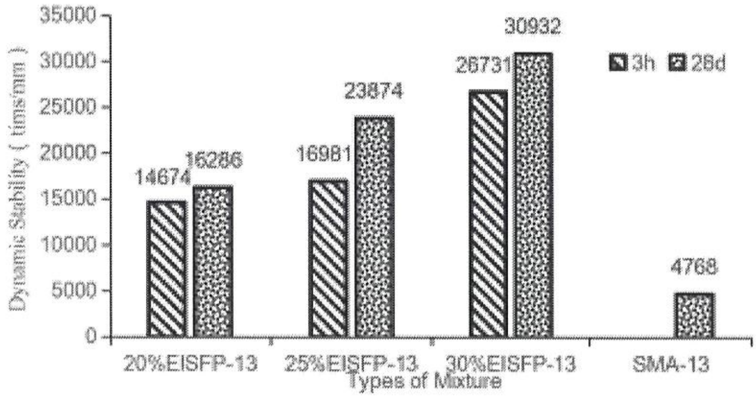

FIGURE 1 Dynamic stability of different types of mixtures

As can be seen from Figure 1.Whether EISFP-13 was cured for 3 hours or 28 days, the dynamic stability of EISFP-13 is increasing gradually with the increase of the void fraction from 20% to 35%.It shows that the ability of resisting high temperature deformation is further strengthened. The analysis shows that the main reason is the increase of void fraction and grouting material, which enhances the rigidity of EISFP-13. In addition, under the same void fraction, the dynamic stability of 3-hour EISFP-13 can reach more than 70% of that of 28-day EISFP-13. The results show that the early-strength EISFP has the characteristics of high early strength and fast strength growth. Compared with SMA-13, the dynamic stability of EISFP-13 is much higher whether it was maintained for 3 hours or 28 days. The results show that the EISFP-13 has super high temperature stability.

3.2 Low Temperature Stability of EISFP

Low temperature trabecular bending test of EISFP-13 specimens and SMA-13 asphalt mixture were carried out to obtain the performance as shown in Table 6.

TABLE 6 Bending test of low temperature trabecular with different mixture types

Mixture types	Flexural tensile strength (MPa)		Maximum flexural strain (με)		Modulus of flexural stiffness (MPa)	
	3h	28d	3h	28d	3h	28d
20%EISFP-13	8.71	9.63	3014	2826	2890	3408
25%EISFP-13	9.35	10.71	2857	2734	3273	3917
30%EISFP-13	9.82	11.48	2764	2521	3553	4554
SMA-13	/	8.27	/	3135	/	2638

It can be seen from Table 6, under the same void fraction condition, the flexural tensile strength and modulus of flexural stiffness of EISFP-13 maintained for 3 hours are lower, and the maximum flexural tensile strain is larger than that of EISFP-13 maintained for 28 days. The main reason is the incomplete hydration reaction of cement-based grouting material during 3-hour maintaining time, and the low strength of grouting material results in the low flexural and tensile strength ofEISFP-13. However, the flexural strength of the EISFP-13 maintained for 3 hours can also reach more than 85% of that maintained for 28 days. Under the same maintaining time condition, with the increase of void fraction, the flexural tensile strength and modulus of flexural stiffness gradually increase, and the maximum flexural strain gradually decreases, which indicates that the low temperature crack resistance of EISFP-13 decreases with the increase of void fraction. Compared with SMA-13 asphalt mixture, the flexural tensile strength and modulus of flexural stiffness of EISFP-13 are larger, and the maximum flexural tensile strain is smaller. The results show that the low temperature performance of EISFP-13 is slightly worse than that of SMA-13 asphalt mixture, but the maximum bending strain can meet the technical requirements of the current specifications [11]for bending strain not less than 2500×10^{-6}.

3.3 Water Stability Performance of EISFP

Water-immersed Marshall test was carried out on EISFP-13 specimens and SMA-13 asphalt mixture. The residual stability was obtained as shown in Figure 2.

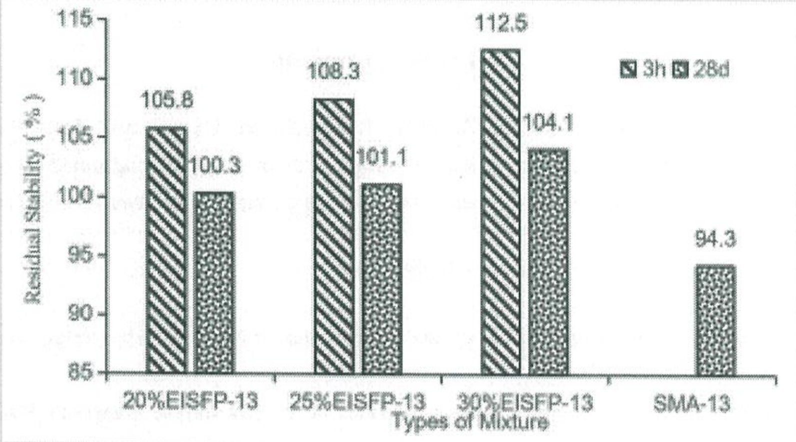

FIGURE 2 Residual Stability of Different Mixture Types

As can be seen from Fig. 2, under the same void fraction, the residual stability of EISFP-13 maintained for 3 hours is greater than that of EISFP-13 maintained for 28 days. The analysis shows that the two groups of specimens need to be maintained in water at 60℃ for 30 minutes and 48 hours respectively in the Water-immersed Marshall test. The strength of the EISFP-13 maintained for 3 hours specimens increased greatly during 48 hours of curing, so the residual stability of the specimens was greater. The hydration reaction of the EISFP-13 specimens with 28 days of curing tended to be stable basically, so the residual stability did not change much. In addition, with the increase of void fraction, the residual stability of irrigated semi-flexible pavement tends to increase, and all of them exceed 100%.The residual stability of EISFP-13 is much higher than that of SMA-13 asphalt mixture, which indicates that the addition of cement-based grouting material increases the compactness of EISFP-13 and gives the EISFP-13 excellent water damage resistance.

4.CONCLUSION

By studying the influence of different voids (20%, 25%, 30%) and curing ages (3hours or 28days) on the high temperature stability, low temperature stability and water stability of EISFP-13 and SMA-13 asphalt mixture specimens, the following conclusions are drawn:

(1)EISFP-13 has excellent high temperature stability and water stability performance. Under the same curing time (3hours or 28days), with the increase of void fraction, the dynamic stability, residual stability of EISFP-13 gradually improve, the maximum flexural strain and modulus of flexural stiffness gradually deteriorate. It shows that the addition of cement-based grouting material improves its high temperature stability and water stability performance, and reduces its low temperature stability. The appropriate void fraction rate should be selected in the design.

(2) The pavement performance of EISFP-13 maintained for 3 hours can reach more than 70% of that of EISFP-13 maintained for 28 days. Compared with the pavement performance of SMA-13 asphalt mixture, the high temperature stability and water stability performance of EISFP-13 maintained for 3 hours are better, and the low temperature performance is slightly worse.But it can still meet the requirements of technical indicators.

(3) Considering the pavement performance of EISFP maintained for 3 hours, ,it is suggested that EISPF can be used for the road maintenance with high traffic pressure, because it can withstand traffic loads after 3-hour maintenance.

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NOTIFICATION OF ACCEPTANCE

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Paper ID: MEP 499

Paper Title: Influences of Matrix Asphalt on Performance of Irrigated Semi-flexible Pavement

Author(s): Xiaoyong Zou, Xingmin Liang, Wenxiu Wu, Wenkun Wu

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2019年6月

Influences of Matrix Asphalt on Performance of Irrigated Semi-flexible Pavement

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Abstract. In order to find out the suitable asphalt types and corresponding voidage of the Irrigated semi-flexible pavement(ISFP), SBS modified asphalt and 70# road petroleum asphalt were used to form the matrix asphalt mixture with voidage of 10%, 15%, 20%, 25%, 30%, 35%. The Marshall specimens ISFP-13 were formed by pouring the cement-based grouting material into matrix asphalt mixture. Marshall test, rutting test, low temperature beam bending test and Freeze-thaw splitting test were used to evaluate its high temperature performance, low temperature performance and water damage resistance. The test results show that with the increase of voidage, the anti-deformation ability of SBS modified asphalt and 70# road asphalt matrix asphalt mixture becomes worse, but the performance of perfusibility becomes better. The high temperature performance and water stability performance of ISFP-13 are enhanced, but the performance of low temperature anti-fission is worse. Comprehensive consideration of the pavement performance of the base asphalt mixture and ISFP, it is suggested that the suitable voidage of 70# road asphalt in ISFP is 15%-20%, and that of SBS modified asphalt in ISFP is 15%-25%.

Key words: Matrix asphalt mixture; Suitable voidage; Irrigated semi-flexible pavement; Pavement performance

1. INTRODUCTION

Irrigated semi-flexible pavement is a composite pavement structure formed by pouring cement-based grouting material into large void matrix asphalt mixture. It has been widely used in the prevention and treatment of rutting diseases of asphalt pavement[1-2]. Numerous studies have shown that the strength of ISFP is formed by the cement mortar and the interaction between coarse aggregates of asphalt mixture, which improve the pavement resistance to load. At the same time, because of the existence of cement mortar, the high temperature stability, water damage resistance and fatigue resistance of ISFP are much better than ordinary asphalt concrete pavement. But the low temperature performance of ISFP has a certain degree of decline, which is greatly affected by the amount of cement grouting material[3-5]. At present, most of the research focuses on the performance of cement-based grouting material and the effect of the amount of cement-based grouting material on the performance of ISFP. However, little research has been done on the influence of matrix asphalt mixture on the performance of ISFP. The type of asphalt, the hardness and softness of asphalt, the amount of asphalt and the voidage of matrix asphalt mixture will affect the performance of base asphalt mixture, then it affects the performance of ISFP. Besides, the type of asphalt and the voidage of the matrix asphalt mixture will restrict each other, and together affect the performance of the matrix asphalt mixture and ISFP.

In order to find the suitable asphalt and the appropriate voidage of the ISFP. SBS modified asphalt and 70# road petroleum asphalt were used in this paper to study the influence of asphalt type on the performance of ISFP with voidage of 10%, 15%, 20%, 25%, 30% and 35%. Suitable types of asphalt and the appropriate voidage are put forward to guide the construction of ISFP.

2. MATERIAL

The main materials are asphalt binder, basalt aggregate and cement-based grouting material.

2.1 Asphalt

The asphalt used in the test are 70# road petroleum asphalt(70#) and SBS modified asphalt (SBS) produced in Jiangsu Province, China.. The basic performance indexes of the two asphalts were tested according to the specifications[6]. The test results are shown in Table 1.

TABLE 1 Test results of two basic performance indexes of asphalt

Test items	70 #	SBS
Penetration (25℃,100g,5s)/0.1mm	67.2	60.2
Ductility (5℃,5cm/min)/cm	5.7	33.4
Softening Point/℃	48.1	84.6
Flash Point (Opening)/℃	328	318
Density (15℃)/(g/cm^3)	1.027	1.028
Solubility (trichloroethylene)/(%)	99.9	99.8
Dynamic Viscosity (60℃)/Pa.s	1461	12631

2.2 Aggregate

Basalt aggregate produced in Anhui Province was used in the experiment.The particle size of 1# and 2# materials are 5-15mm and 0-5mm. The basic performance indices of aggregates and mineral powder are shown in Table 2.

TABLE 2 Basic performance index of aggregate

Material	1#(BS)	2#(BS)	3#(BS)	Mineral powder(LS)
Apparent Density (g/cm^3)	2.906	2.918	2.889	2.721
Bulk Density (g/cm^3)	2.874	2.853	2.823	/
Water Absorption Rate (%)	0.38	0.78	0.81	/

2.3 Cement-Based Grouting Material

Cement-based grouting material was self-made in laboratory. Water cement ratio of grouting material is 0.3, and the detection indexes are shown in table 3.

TABLE 3 Test results of various indexes of cement-based grouting material

Test Items	Unit	Test Results	Technical Requirement	Age
Fluidity	s	11.7	10~14	-
		12.8	10~16	0.5h
Segregation Rate	%	1.7	≤5	3h
Volume Change Rate	%	0.15	-0.10~0.36	60d
Compressive Strength	MPa	12.6	≥10.0	3h
Flexural Strength	MPa	3.9	≥2.0	

3. PREPARATION OF SPECIMENS

3.1 Design of Matrix Asphalt Mixture

In order to ensure the design voidage of matrix asphalt mixture, volume design method[7] was adopted. And the final ratio of SFP-13 for matrix asphalt mixture is determined as shown in Table 4. The gradation of the obtained matrix asphalt mixture is shown in Table 5.

TABLE 4 Composition of matrix asphalt mixture with different void ratio

Material	Designed Voidage (%)					
Composition	10	15	20	25	30	35
1#	72	76	80	84	90	93
2#	24	20	16	12	6	3
Miner Powder	4	4	4	4	4	4
Asphalt	4.8	4.4	4.0	3.4	3.0	2.8

TABLE 5 Gradation of matrix asphalt mixture with different void ratio

Design Voidage	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
10%	100	75.23	34.26	28.14	21.74	16.58	10.53	9.83	7.74	5.91
15%	100	73.86	30.61	24.15	18.81	14.51	9.47	8.89	7.09	5.51
20%	100	72.48	26.96	20.16	15.89	12.45	8.42	7.95	6.44	5.10
25%	100	71.10	23.31	16.17	12.96	10.38	7.36	7.01	5.79	4.70

30%	100	69.43	17.83	10.18	8.58	7.29	5.78	5.60	4.82	4.09
35%	100	68.01	15.09	7.19	6.39	5.74	4.98	4.90	4.33	3.79

Matrix asphalt mixtures with different voids were prepared from 70# road asphalt and SBS modified asphalt respectively. The optimum asphalt to stone ratio and apparent density of different void fractions are determined by the Cantabro test and the leakage test as shown in Table 6.

TABLE 6 Optimum asphalt-aggregate ratio of matrix asphalt mixture with different voidage

Voidage (%)	Optimum asphalt to stone ratio (%)	Apparent Density (g/cm³)
10	4.9	2.311
15	4.5	2.219
20	4.0	2.118
25	3.5	2.013
30	3.2	1.958
35	3.0	1.879

3.2 Preparation of Test Sample for ISFP

The ISFP specimens are formed by using the mixture proportions of the above-mentioned two kinds of asphalt and six kinds of mixtures with different voids and corresponding asphalt-stone ratios. The forming steps are as follows:

(1)Marshall specimens and rutting plate specimens were formed by Marshall compaction method and rolling method respectively. The size of Marshall specimen is 101.6mm×63.5mm cylinder. Rutting plate specimens with size of 300mm×300mm×50mm are formed.

(2) Cement-based Grouting Material with Water-cement Ratio of 0.3 was prepared by using the laboratory agitator, the stirring speed is 3000r/min and the stirring time is 3 min. The grouting material is poured into the matrix asphalt mixture. After the matrix asphalt mixture is filled full, the superfluous slurry on the surface were removed.

(3) The specimens after filling were put into standard maintenance room for 28 days, and then the road performance was tested.

4. PERFORMANCE OF MATRIX ASPHALT MIXTURE

4.1 Marshall Test Results

Marshall stability test and Cantabro loss particle test were carried out for the matrix asphalt mixture with different types and voids of asphalt. The results are shown in Fig. 1.

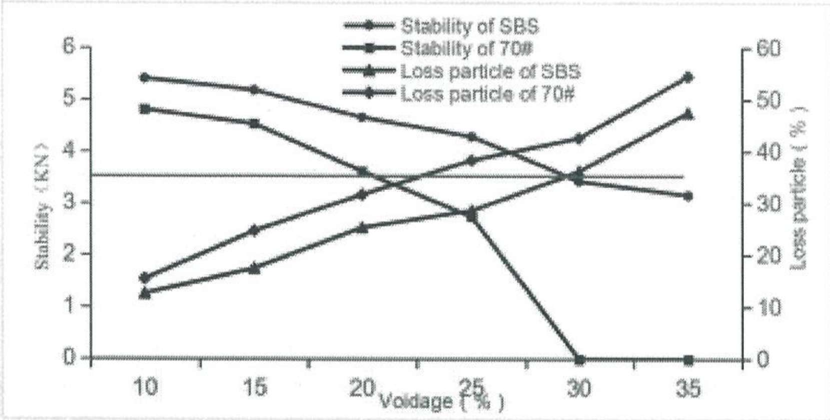

FIGURE.1 Marshall test results of matrix asphalt mixture

From Fig.1, it can be found that with the increase of voidage of matrix asphalt mixture, Marshall stability of 70# road asphalt mixture decreases gradually, and the Cantabro loss particle increases gradually. The results show that the increase of voidage decreases the resistance of matrix asphalt mixture to deformation and spalling. It can also be found that the voidage of matrix asphalt mixture prepared from 70 # road asphalt is 30% and 35%. It's Marshall stability value is 0 KN.Mainly because the matrix asphalt mixture has been dispersed when it is cured in a water bath at 60℃. Therefore, the voidage of matrix asphalt mixture should not be too large. With the same voidage, the Marshall stability of the matrix asphalt mixture prepared by SBS modified asphalt is greater than that of 70 # road asphalt mixture, and Cantabro loss particle is smaller. The main reason is that SBS modified asphalt has better high temperature performance and viscosity performance. Considering the Cantabro loss particle and the Marshall stability of the matrix asphalt mixture, the index requirement should greater than 3.5KN. It is preliminarily suggested that the suitable voidage of matrix asphalt mixture for 70 # road asphalt should not be more than 20%, and that of SBS modified asphalt should not be more than 30%.

4.2 Perfusion Feasibility Test Results

The perfusion time and perfusion rate were used as the evaluation index of perfusion feasibility. Pouring time is the time when grouting material begins to pour into grouting material and no longer penetrates downward. Perfusion rate is the full degree of voidage grouting material[8]. For Marshall specimens of asphalt mixtures with voids of 10%, 15%, 20%, 25%, 30% and 35%, the time of permeability is determined respectively. After the hardening strength of grouting material is formed, the perfusion rate of grouting material is tested. The results are shown in Figure 2.

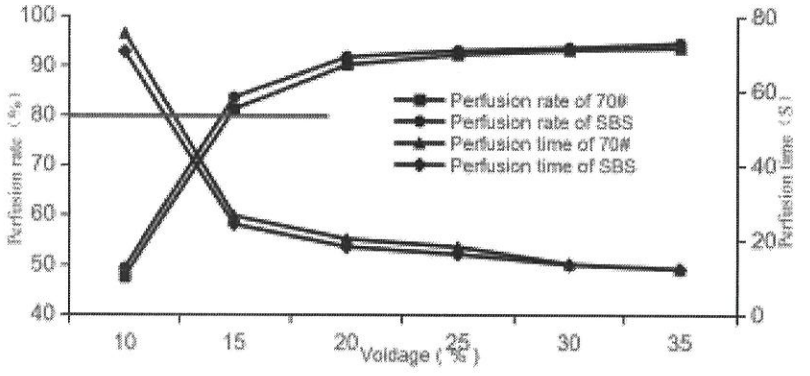

FIGURE.2 Test results of perfusion rate and perfusion time

It can be seen from Fig.2 that the perfusion rate and perfusion time curves of 70# road asphalt and SBS modified asphalt have the same trend, and the difference is not significant. It shows that the type of asphalt has little effect on the filling feasibility of matrix asphalt mixture. With the increase of voidage, the perfusion rate of matrix asphalt mixture increases and the perfusion time decreases, which indicates that increasing voidage can improve the feasibility of perfusion. The perfusion rate of matrix asphalt mixture should not be too low, otherwise it will increase the internal voidage of the ISFP and reduce the pavement performance. The perfusion time of matrix asphalt mixture should not be too long, otherwise it will affect the construction efficiency. The perfusion rate of grouting material should not be less than 80% according to Shilei et al[9].It is suggested that the voidage of matrix asphalt mixture of 70 # road asphalt and SBS modified asphalt should not be less than 15%.

5. PERFORMANCE OF ISFP

Rutting test, low-temperature beam bending test and freeze-thaw splitting test were carried out for different types of asphalt and different voids of ISFP-13[10].

5.1 High Temperature Stability Performance

The rutting test was used to evaluate the high temperature stability of ISFP-13, and the dynamic stability was used to characterize the high temperature stability. The test conditions are 60±1℃ and 0.7±0.05MPa. The rutting stability test results of ISFP-13 are shown in Figure 3.

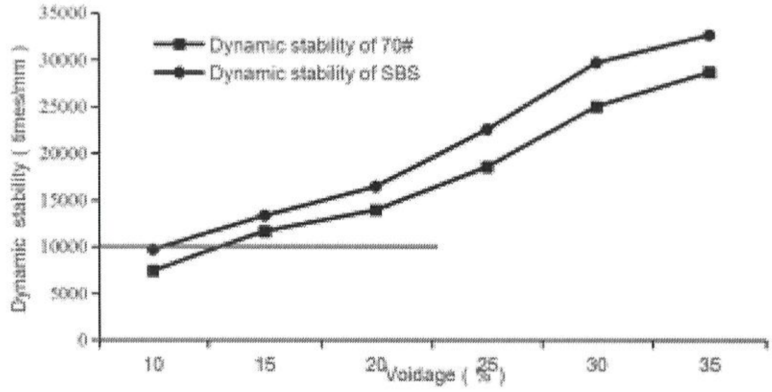

FIGURE.3 Rutting test results

From the test results of Fig. 3, it can be seen that the rutting stability of ISFP-13 prepared by 70# asphalt and SBS modified asphalt increases gradually with the increase of void fraction. It shows that the addition of cement-based grouting material greatly improves the high temperature deformation resistance of ISFP-13. Comparing the rutting stability of two types of asphalt with the same voidage, the rutting stability of ISFP-13 prepared by SBS modified asphalt is better. According to the index requirement that rutting stability of semi-flexible pavement should not be less than 10000 times/mm.The ISFP made of 70# road asphalt and SBS modified asphalt with voidage should not be less than 15% can meet the requirements.

5.2 Low Temperature Stability Performance

The low temperature crack resistance of the mixture was evaluated by low temperature beam bending test, and it's low temperature performance was evaluated by maximum bending strain and bending stiffness modulus. The test conditions are that the temperature is -10±0.5℃, the rutting plate was cut into prismatic beam of 250±2.0mm in length, 30±2.0mm in width and 35±2.0mm in height, a span was 200±0.5mm and a loading rate was 1 mm/min. The test results are shown in Fig. 4.

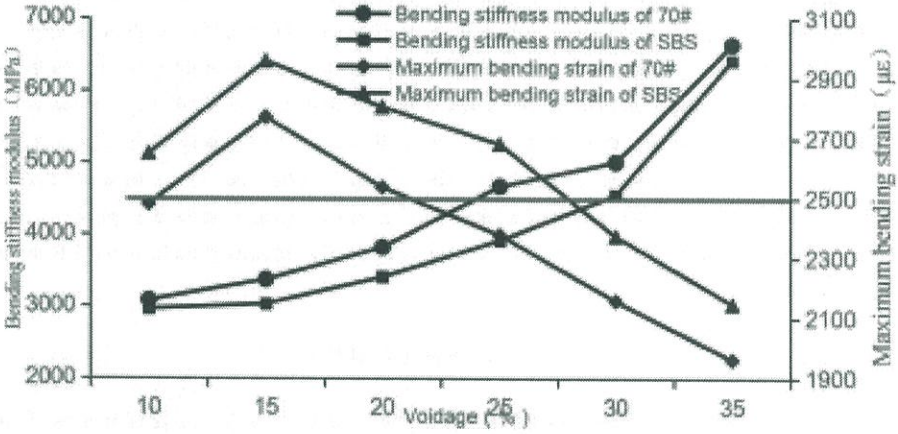

FIGURE.4 Results of low temperature beam bending test

According to Fig. 4, with the increase of voidage, the bending stiffness modulus of ISFP-13 made of 70# road asphalt and SBS modified asphalt increases gradually, and the corresponding maximum bending strain shows a downward trend. It shows that the low-temperature deformation ability of ISFP-13 is getting worse. It is also found that the maximum bending strain increases first and then decreases. The analysis shows that when the voidage is between 10% and 15%, there are many voids in ISFP-13 because of its small voidage and poor perfusion ability. And it is easy to produce stress concentration phenomenon, so the resistance to deformation ability is poor. Compared with 70# asphalt pavement, the bending stiffness modulus of ISFP-13 prepared by SBS modified asphalt is smaller and the maximum bending strain is larger under the same voidage, which indicates that its low temperature performance is better. The main reason is that the deformation creep property of SBS modified asphalt is better at low temperature. At the same time, it is found that the suitable voidage of ISFP-13 prepared by different asphalt types is different. According to the specifications, the maximum bending strain should not be less than 2500×10^{-6}. It is suggested that the voidage of 70# road asphalt in ISFP should not be more than 20%, and that of SBS modified asphalt in ISFP should not be more than 25%.

5.3 Water Stability Performance

Freeze-thaw splitting test is used to evaluate the water damage resistance of mixtures during freeze-thaw cycles. Freeze-thaw splitting strength ratio(TSR) index is used to evaluate water stability.The specimen was first saturated in vacuum to frozen for 16 hours at -18℃, and then immersed for 24 hours at 60℃. Splitting test was carried out at 25℃ and results are shown in Fig. 5.

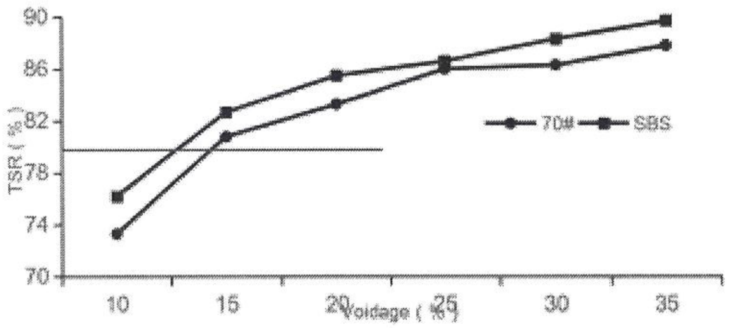

FIGURE.5 Test results of freeze-thaw splitting

According to the results of freeze-thaw splitting test, it can be seen that with the increase of voidage, the TSR increases gradually, which indicates that the ability of freeze-thaw damage resistance of ISFP-13 increases gradually. It is mainly the addition of cement-based grouting material greatly enhances the compactness of ISFP-13 and reduces the possibility of water damage. However, it can be found that when the voidage is less than 15%, the TSR can not meet the specification requirements of not less than 80%. It is concluded that when the voidage is less than 15%, there are many residual unfilled voids in ISFP, which will cause severe freeze-thaw damage under the action of freeze-thaw water erosion. Therefore, voidage of 70 # road asphalt and SBS modified asphalt in ISFP should not be less than 15%.

6. CONCLUSION

By investigating the influence of different asphalt types and voids on pavement performance of ISFP, the following conclusions are drawn:

(1) With the increase of voidage, the Marshall stability of matrix asphalt mixture decreases gradually, Cantabro loss particle increases gradually, and the perfusion feasibility improves gradually. The performance of SBS modified asphalt matrix asphalt mixture is better than 70 # road asphalt. Considering the performance of matrix asphalt mixture, the suitable voidage is 15% - 30%.

(2) High temperature dynamic stability and freeze-thaw splitting strength ratio of ISFP-13 gradually increase with the increase of voidage, but the maximum Bending strain at low temperature gradually decreases. The high temperature stability and water stability of ISFP-13 prepared by SBS modified asphalt are similar to those of SFP-13 prepared by 70# road petroleum asphalt, but it's low temperature performance is better. Considering the pavement performance of ISFP, the suitable voidage is 15%-25%.

(3)Considering comprehensively the influence of SBS modified asphalt and 70# road asphalt on the performance of matrix asphalt mixture and ISFP. It is suggested that the suitable voidage of 70 # road asphalt in ISFP should be 15% - 20%, and that of SBS modified asphalt in ISFP should be 15% - 25%.

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(54)发明名称

级配碎石灌入式半柔性复合路面混合料及路面施工方法

(57)摘要

本发明涉及级配碎石灌入式半柔性复合路面混合料，包括如下质量分数的组分：级配碎石100份；水4-6份；灌浆料6-10份；所述灌浆料包括水泥、水性丙烯酸树脂、火山灰材料和水，所述罐浆料灌入向所述级配碎石中。采用本发明的半柔性复合路面混合料在常温下即可施工，可有效的解决沥青路面车辙病害问题，改善路面的耐久性能；降低灌入式半柔性路面热拌施工对环境的污染问题；提高灌入式复合路面的施工效率，降低生产成本。

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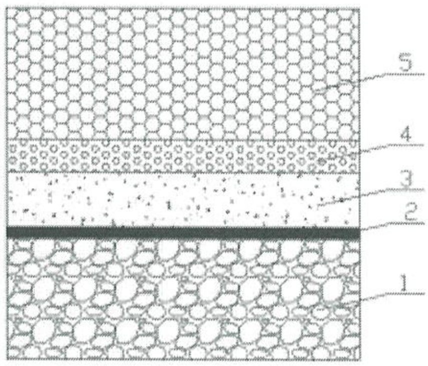
(54)发明名称

一种复合路面结构及养护方法

(57)摘要

本发明公开了一种复合路面结构，属于道路工程养护领域。所述复合路面结构包括包括从下到上依次成型的路面承载基层、基层粘结密封层、缓冲层、碎石封层、复合路面层。该结构具备抗变形能力强、受力均匀、强度增长快的优点，缩短了路面的养护封闭交通时间，可以大幅提高路面的使用寿命，减少路面周期养护成本。同时本发明还公开了一种复合路面结构及养护方法。



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