FIG. 1. Rollpave in the Netherlands (Beuving, 2007)

FIG. 2. Four-point bending test of high ductility concrete (University of Michigan)

REASEARCH METHOD

The development of a rollable road surface firstly requires the appropriate concrete formula from which the concrete layer can be made with TmK. The conception and manufacture of the surface is performed in cooperation with the Institute of Building Materials Research of the RWTH Aachen University (ibac). The mixture design is determined on the basis of the results from the collaborative research center SFB 532 (Hegger et al, 2011). As reinforcement, 2 % KURALON™-PVA fiber of the type RECS15 3 with a length of 12 mm and a diameter of 40 µm was applied. The tensile strength is 1600 MPa at the maximal strain of 6% and the tensile modulus lie in 41 GPa. Additionally, a glass fiber textile grid was planted in two layers.

A sufficient skid resistance of this fine-structured, smooth surface is ensured by appropriate surface treatment. The fine surface structure is generally achieved by applying stone grains finer than 0.3 mm. Larger grains would affect the cracking alleviation and the bridging function of the fibers. The necessary structure of the TmK layer in favor of skid resistance should be achieved without affecting the mortar on the surface and the reinforcement of the fiber. Conventional methods, including exposed aggregate concrete, sweeping with an artificial turf, brush or burlap as well as sharpening and grooving and so on, are less appropriate for this case because direct treatment on the surface of TmK may destroy the fiber and the interaction between the fiber and the concrete. Therefore, the concrete surfaces were spread firstly with epoxy resin and then with various chippings of the size 2 – 5 mm following the treatment in the acoustical researches (Beckenbauer, 2003; Beckenbauer, 2008; Sandberg and Ejsmont, 2002). A finished surface is presented in **FIG. 3**, left.

In order to describe the drainability of the surface (aquaplaning potential) and the polishing resistance (durable skid resistance and strength), the various surfaces were polished with the Aachener Raveling Tester **(FIG. 3**, right**)** following the experiences in

(Wang et al, 2013; Steinauer et al, 2012; Schacht et al, 2011). This tester simulates the polishing effect under a real car wheel of 200 kg. The polishing effect is exerted through a translational and a rotational movement of the base plate. In order to accelerate the loading, polishing agents and water will be added in certain rates.

FIG. 3. Test plate made of TmK with spreading chips on an asphalt substrate (left). Aachener Raveling Tester (Right)

After each polishing step, the plate specimen will be weighted and the change of the mass will be determined as the grain loss. The micro-texture is described by the Pendulum Test Value (abbreviated as PTV) from the pendulum test according to EN 13036-4, while the macro-texture depth (MTD) is determined with the sand patch method according to EN 13036-1. The quality of the binding conditions will be evaluated by the mass loss of the specimen, meaning the mass of the loosened grains that break out from the surface.

TEST RESULTS

The affinity of the binder material to the stone grains was very different when using different stone types, as shown in **FIG. 4**. Granite and Granusil show very good affinity with very few grain break outs. In the case of Greywacke and Basalt, many grains were loosened by the polishing load; some of the concrete surfaces were even completely exposed. By means of a linear regression analysis with multiple variables, the effect of the grain size of the chippings and the polishing duration on the grain breaking-out was investigated, as shown in **Table 1**. It makes clear that with larger grains and increasing polishing duration more grain breaking-out happens. The amount of breaking-out for Granite and Granusil is influenced by the grain size and polishing duration to a smaller extent than that for Basalt and Greywacke.

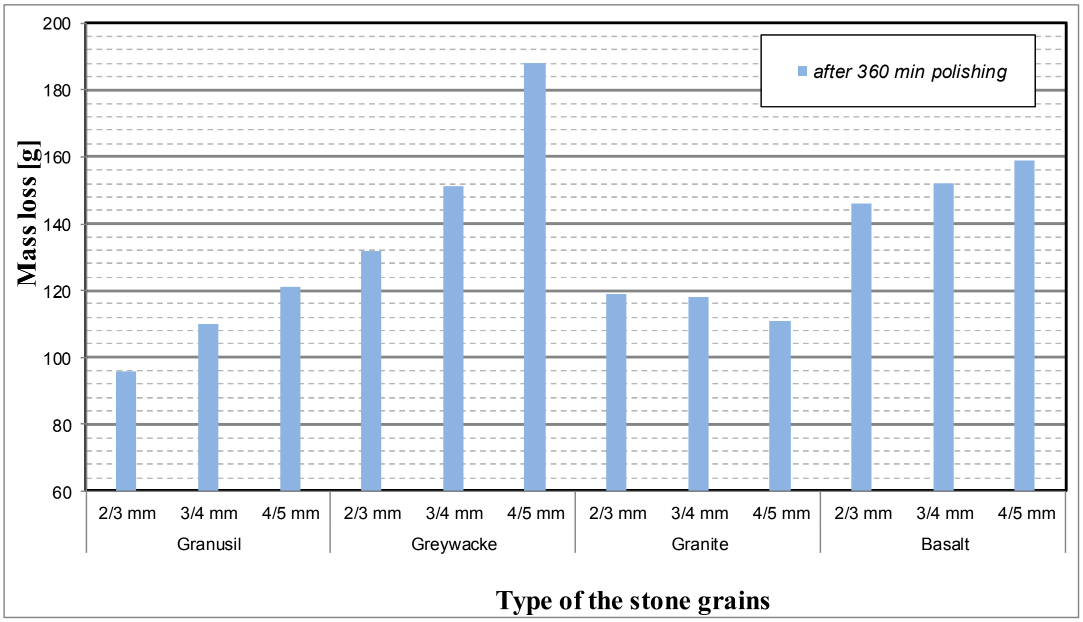

FIG. 4. Breaking-out of grains

Table 1. Regression coefficients of three different target values with one grain size and polishing duration (Y = a + b · grain size [mm] + c · polishing duration [min])

	Stone types	R^2	a	b	c
Y = breaking-out amount	Basalt	.830	-13.972	9.500	.423
	Granite	.820	17.306	-.500	.322
	Granusil	.821	-7.778	6.333	.303
	Greywacke	.822	-35.139	15.833	.436
Y = Pendulum Test Value (PTV)	Basalt	.967	75.542	-1.483	-.039
	Granite	.972	75.142	-.850	-.033
	Granusil	.886	70.597	-.417	-.026
	Greywacke	.830	79.114	-1.517	-.027
Y = Macro-texture depth (MTD)	Basalt	.934	.908	.424	-.001
	Granite	.899	1.513	.157	-.001
	Granusil	.967	.924	.317	-.001
	Greywacke	.910	.882	.343	-.001

To evaluate the effect of the polishing on the micro-texture, the pendulum test was performed on the test plates. Before the polishing, the PTV of all variants is about 70 or higher. Through polishing, the skid resistance is reduced to a different extent for all variants. Also after 360 minutes, the Greywacke shows the highest PTV, as shown in **FIG. 5**. Granite, Granusil and Basalt 2/3 mm have a PTV of about 60. Only the rest Basalt plates have a comparable low PTV of about 55. The regression shown in **Table 1** indicates that the skid resistance decreases with higher grain size and longer polishing duration. Greywacke and Granusil have a higher c-value and therefore show less skid resistance reduction than Basalt und Granite.

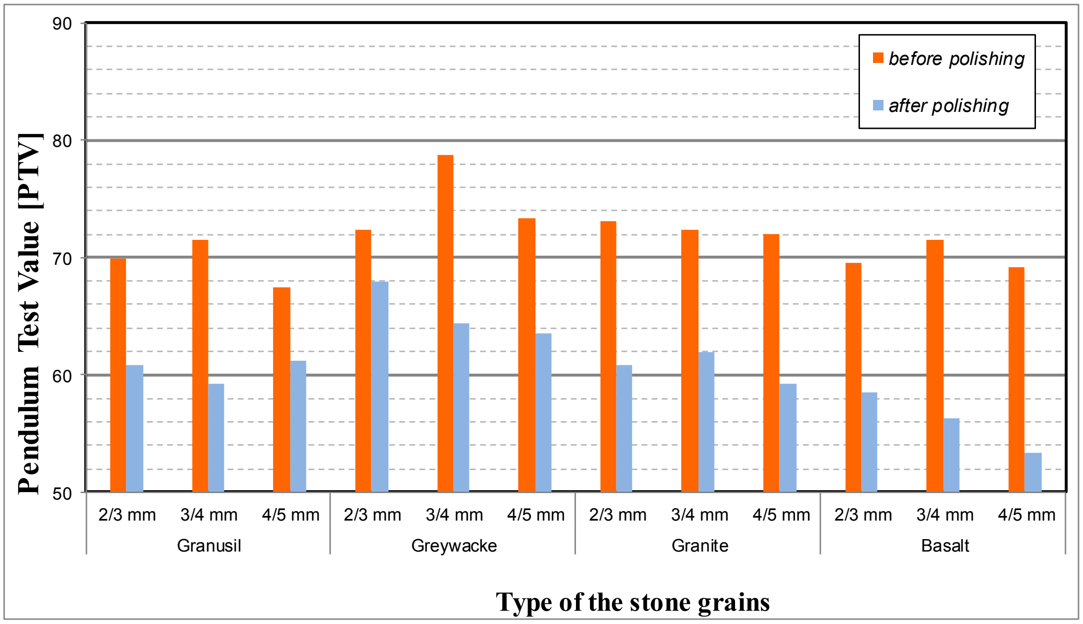

FIG. 5. Development of the SRT value

For a closer evaluation of the macro-texture, the mean macro-texture depth (MTD) was determined with the sand patch method, as shown in **FIG. 6**. With higher grain size, the texture depth is larger. The protruding tops are strongly worn by the polishing. Before polishing, the texture depth lies between 1.6 and 3 mm. This value is reduced gradually by 0.3 in the course of 360 min of polishing. According to the regression analysis as shown in **Table 1**, it is obviously that the polishing load leads to a smoothening of the macro-texture. The regression coefficient c shows a value of –0.001 for all stone types and is therefore independent on the stone types. Additionally, it can be inferred from the results that greater grain size lead to higher surface texture depth.

In summary, the polishing effect smoothens the micro-texture and macro-texture; as a result, the skid resistance decreases in the long term and the drainability will be affected. Smaller grains have better skid resistance than bigger grains after polishing. For the macro-texture, coarser grains are better. Finer grains have a better affinity and therefore fewer grains break out. The Greywacke shows the highest skid resistance and Basalt the smallest. Regarding the grain loss, Granite and Granusil are better than Greywacke and Basalt. Granite and Granusil have a brighter color than Greywacke and Basalt. This favors the reflection performance and results in less heating up. Granite 2/3, 3/4 and Granusil 2/3, 4/5 are especially recommended. These variants have a very good drainability, higher affinity, high skid resistance and are brighter than Greywacke and Basalt.

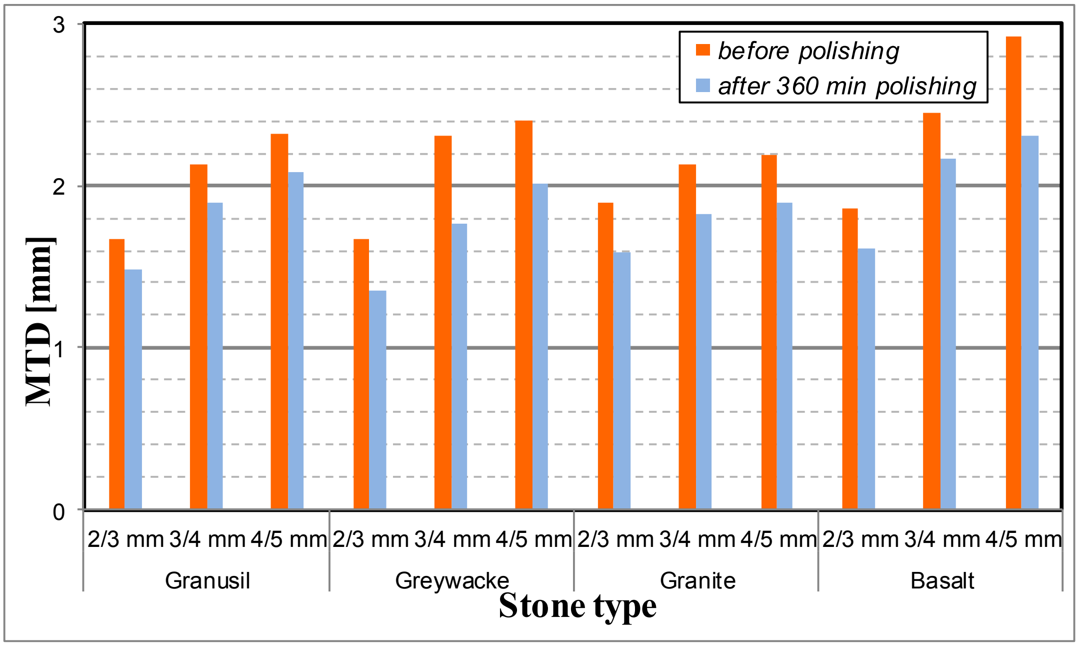

FIG. 6. Development of the texture depth

CONCLUSIONS

It can be concluded that the application of industry pre-fabricated textile concrete with short fiber is/will be feasible for practice. An aimed designing and structuring of the surface can secure very positive using performances. The durability however depends on both the construction quality and the stone grains as well as on the properties of the aggregates.

With this technique, the winter distresses can be removed within only a few hours. The new road surface can be opened to traffic as soon as possible. Particularly for the drivers this will indirectly save much time which would otherwise be wasted on long-term construction sites that interfere with traffic. Therefore, it has the potential to contribute to durable road structures and the sustainability of road engineering.

The presented research proved the feasibility of this kind of road surface. It still lacks of field experience regarding the construction methods and using performances. The test results obtained in the laboratory thus still need in-situ verification. As a step to the modular road surface of the future, the rollable pavement provides the ideal basis of an "intelligent" road equipped with sensors, which prepares relevant information for the road users. In this way, the road surface could be equipped directly in the factory with corresponding technologies to collect environment and traffic information.

ACKNOWLEDGMENTS

The basis of this work was performed in the scope of the project STE 9083-1 financed by the DFG (German Research Foundation). The authors thank Prof. W. Brameshuber and Mr M. Hinzen from the Institute of Building Materials Research of the RWTH Aachen University (ibac) for their support in specimen preparation in the scope of a student thesis.

REFERENCES

Beckenbauer, T. (2003). "Reifen-Fahrbahn-Geräusche – Minderungspotenziale der Straßenoberfläche." Müller BBM, Planegg, Fortschritte der Akustik – DAGA.

Beckenbauer, T. (2008). "Physik der Reifen-Fahrbahn-Geräusche, Geräuschentstehung, Wirkungsmechanismen und akustische Wirkung unter dem Einfluss von Bautechnik und Straßenbetrieb" in: 4. Informationstage Geräuschmindernde Fahrbahnbeläge in der Praxis – Lärmaktionsplanung.

Beuving, E. (2007). "European developments in asphalt mix characterization" in: TPA Conference, Ungarn, May 04, 2007.

Brameshuber, W., Hinzen, M. (2011). "Tragverhalten von Textilbeton mit Kurzfasern" in: 6th Colloquium on Textile Reinforced Structures (CTRS6) 187.

Hegger, J., Brameshuber, W., Gries, T. (2011). "Textilbewehrter Beton – Grundlagen für die Entwicklung einer neuartigen Technologie" Sonderforschungsbereich SFB 532, Forschungsantrag 2. Hj. 2008 2009 2010, 1. Hj. 2011, RWTH Aachen.

Li, V. C. (2003). "On Engineered Cementitious Composites (ECC) - A Review of the Material and Its Applications" Journal of Advanced Concrete Technology, Vol. 1, Issue 3.

Mechtcherine, V. (2009). "Entwicklung, Prüfung und Anwendung - Hochduktiler Beton mit Kurzfaserbewehrung" Beton 3.

Sandberg, U.; Ejsmont, J. A. (2002). "Tyre/Road Noise Reference Handbook." Informex, Kisa.

Schacht, A., Wang, D., Steinauer, B. (2011). "Untersuchung der Kornausbrüche bei poroelastischen Fahrbahnbelägen mit dem Aachener Ravelling Tester (ARTe)" Bauingenieur, S. 160-168.

Steinauer, B., Wang, D., Stanjek H. (2012). "Erhöhung der Verkehrssicherheit durch gute Griffigkeitswerte während der gesamten Gebrauchsdauer von hochbelasteten Straßen." Forschung Straßenbau und Straßenverkehrstechnik Heft 1070, Bundesministerium für Verkehr, Bau und Stadtentwicklung, Wirtschaftsverlag.

University of Michigan: physorg.com. http://ace-mrl.engin.umich.edu//index.html
Wang, D., Steinauer, B., Stanjek, H., Stanjek, C., Chen, X., Oeser, M. (2013). “Auswirkung einer kombinierten Polier- und Frostbeanspruchung auf die Griffigkeit der Fahrbahnoberfläche“ Bauingenieur 5.

Evaluation of Polyester Grout for Use in Dowel Bar Retrofit Treatments

DingXin Cheng[1], P.E., Brian Winter[2], Lerose Lane[3], P.E. and Doran Glauz[4], M. ASCE, P.E.

[1] Director, California Pavement Preservation Center, 35 Main St. #205, Chico, CA 95929, USA. Email: dxcheng@csuchico.edu
[2] Student research assistant, California Pavement Preservation Center, 35 Main St. #205, Chico, CA 95929, USA. Email: southpaw9999@sbcglobal.net
[3] Senior Pavement Preservation Engineer, California Pavement Preservation Center, 35 Main St. #205, Chico, CA 95929, USA. Email: lerose@theskybeam.com
[4] Senior Materials and Research Engineer, California Department of Transportation, 5900 Folsom Blvd, Sacramento, CA 95819, USA, Email: doran_glauz@dot.ca.gov

ABSTRACT: Dowel bar retrofit (DBR) is an effective concrete pavement preservation technique to restore the load transfer efficiency at joints of the jointed plain concrete pavement. So far, more than 5 million dowel bars have been installed in the United States. While the majority of DBR projects were successful, some have had issues, including early failures. Recently, it has been proposed that polyester grout may perform better than conventional DBR grout materials. Polyester grout is a grout using polymerized resin as binder instead of fast setting concrete backfill material. Compared to conventional grout materials containing high alumina or magnesium phosphate materials, the polyester grout has more flexibility, better adhesion with the existing pavement, and a low viscosity for better consolidation.

This paper presents the results of evaluation of performance of US 50 DBR project constructed with polyester grout in 2010 for the California Department of Transportation. In 2012, a team of researchers and engineers conducted visual inspections and non-destructive tests. Core extractions were also performed at a later date based on the visual inspection and non-destructive test results. In the laboratory, the tests included shear bonding strength tests as well as dowel bar pull out tests. The results in both the laboratory and field showed that the polyester grout has worked very well to date.

Key Words: Dowel Bar Retrofit, Jointed Plain Concrete Pavement, Polyester Grout, Backfill Materials, Pavement Performance

INTRODUCTION

In jointed plain concrete pavements (JPCP), load transfer efficiency (LTE) refers to the effectiveness of transferring load from one slab across a joint to the adjacent slab as traffic passes over the joint. The LTE of JPCP depends on aggregate interlock at the joints to transfer dynamic loads as well as support from the base materials. As the joints age and deteriorate due to traffic loadings, aggregate interlock is lost and LTE decreases. Dowel bar retrofit (DBR) is an effective pavement preservation technique to restore the LTE at the JPCP joints. DBR should be selected for concrete pavements that are structurally sound and exhibit low load transfer at joints and transverse cracks. It is normally not used on pavements that are in poor condition.

More than 20 State Departments of Transportation (DOTs) in United States have used DBR to increase load transfer and increase the service life of JPCP (Winter et al. 2012). So far, more than 5 million dowel bars have been installed in the United States. While the majority of DBR projects are successful, some have had issues including early failures. For example, North Dakota DOT had grout shrinkage cracks and loss of bonding between grout and existing concrete while Wisconsin DOT reported a project with significant patching material failure due to lack of freeze- thaw durability (Pierce 2003). Through past studies, California DOT (Caltrans) found that DBR is an effective rehabilitation and preservation strategy for improving joint load transfer efficiency across transverse joints and cracks. However, distresses on various projects were reported statewide and the issues included debonding, deleterious material between the grout and existing pavement, poor grout consolidation, and loss of bonding between grout and existing concrete. Conventional concrete backfill materials haven't always performed properly (Pyle et. al 2004, Glauz et.al 2002).

Based on previous work in California (Krauss 1985), it was proposed that polyester grout may perform better than conventional DBR grout materials. Polyester grout is a grout using polymerized resin as binder instead of cement. Compared to conventional grout materials containing high alumina or magnesium phosphate, the polyester grout has more flexibility, better adhesion with existing concrete, and low viscosity for better consolidation. Therefore, Caltrans constructed its first pilot project using polyester grout as backfill materials for over 60,000 dowel bars installed on US 50 in Sacramento, California during the summer of 2010.

EXISTING PAVEMENT STRUCTURE

The original pavement structure consisted of a 0.70' (215 mm) layer of portland cement concrete over a 0.45' (140 mm) Class A Cement Treated Base (CTB CL A) supported by a 0.50' (150 mm) Aggregate Subbase (AS).

TEST SECTIONS AND MATERIALS

Four test sections were established for this study. Each section comprised 25 contiguous joints of the JPCP. The four test sections had the following features:

- No treatment (Control)
- DBR
- DBR with HMA overlay
- HMA overlay

For DBR dowel bars were placed into slots in the JPCP and encased with a low-shrinkage polyester grout. The slots measure approximately 36 inches (914 mm) long (18 inches (457 mm) extending into each slab from the joint), 2.5 inches (64 mm) wide and 6 inches (152 mm) deep. Each wheel path included three dowel bars (for a total of six) at each joint. The dowel bars are smooth, round, 1.5 inch (38 mm) diameter epoxy coated steel approximately 18 inches (457 mm) in length.

The HMA overlay is 1 inch (25mm) of open graded rubberized hot mix asphalt (RHMA-O).

All sections were ground smooth, for ride quality, after the DBR and before the RHMA-O was applied, including the no treatment section.

TEST SECTION VISUAL EVALUATION

The initial visual inspections on the polyester test sections were performed on January 17 and 18, 2012. This work included visual inspections of the four sections shown in Table 1.

Table 1 Four Test Sections for the DBR Evaluation Project

Section	DBR section, No overlay	DBR with overlay	No DBR with overlay	No DBR, No overlay (Control Section)
Location	EB US-50, East of Sunrise Blvd	EB US-50, East of Mather Field Rd	EB US-50, East of Mather Field Rd	WB US-50, West of Sunrise Blvd
Overall Condition	Joints: minor spalling Slabs: minor surface spalling; about half of the slabs displayed some cracking at corners or at mid-span. DBR: overall condition good	Wear surface: no defects of any kind	Wear surface: no cracking; minor raveling	Joints: minor spalling Slabs: some small mid-span cracks, 75 percent of slabs are missing the inside corner, most have been patched with asphalt

EVALUATION of DBR USING NON-DESTRUCTIVE TESTING

Four different NDT tests were performed: falling weight deflectometer (FWD), tomography with MIRA technology, the Spectral Analysis of a Surface Wave (SASW), and Slab Impulse Response (SIR). The FWD evaluation is discussed in detail. Other NDT tests are described briefly.