JOURNAL OF TRAFFIC AND TRANSPORTATION ENGINEERING (ENGLISH EDITION) 2017; X (X): 1–8

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/jtte

Original Research Paper

Experimental investigation of asphalt mixture containing Linz-Donawitz steel slag

Jens Groenniger, Augusto Cannone Falchetto, Ivan Isailović, Di Wang, Michael P. Wistuba*

Braunschweig Pavement Engineering Centre (ISBS), Department of Civil Engineering, Technische Universität Braunschweig, Braunschweig 38106, Germany

HIGHLIGHTS

- Asphalt mixtures with 100% Linz-Donawitz (LD) slag were produced for the first time and performance characteristics were investigated.
- A wide range of performance related tests were conducted to assess the suitability of LD slag in asphalt mixtures.
- Suitability of LD slag for asphalt pavement construction was shown.

ARTICLE INFO

Article history:
Received 12 December 2016
Received in revised form
8 May 2017
Accepted 9 May 2017
Available online xxx

Keywords:
Linz-Donawitz slag
Low-temperature cracking
Permanent deformation
Fatigue

ABSTRACT

Standard asphalt mixtures for road infrastructures consist of natural aggregate and bitumen. A number of research efforts have successfully investigated the possibility of replacing the conventional aggregate skeleton with industrial by-products such as slag originating from steel production process. However, little is known on the effect of steel slag on the mixtures performance properties such as resistance to low-temperature cracking and to permanent deformation, stiffness and fatigue. This paper presents a comprehensive investigation on the fundamental performance properties of different types of asphalt mixtures prepared with 100% LD slag aggregate and a conventional asphalt mixture containing natural Gabbro aggregate. Sophisticated testing methods were used to evaluate the key performance parameters for the set of asphalt mixtures investigated. In this study, low temperature cracking was addressed through thermal stress restrained specimen tests. Penetration tests and cyclic compression tests were used to evaluate the response of asphalt binder and asphalt mixture to permanent deformation due repeated loading, respectively. The cyclic indirect tensile test was selected for investigating both stiffness properties and fatigue resistance. For this purpose the complex stiffness modulus was measured to quantify material stiffness under different temperature and loading conditions providing information on the visco-elasto-plastic material behavior. Fatigue tests were used to determine the progressive and localized material damage caused by cyclic loading. The experimental results indicate that asphalt mixtures prepared with LD

* *Corresponding author*. Tel.: +49 531 391 62064; fax: +49 531 391 62063.
E-mail addresses: j.groenniger@tu-bs.de (J. Groenniger), a.cannone-falchetto@tu-bs.de (A. Cannone Falchetto), i.isailovic@tu-bs.de (I. Isailović), di.wang@tu-bs.de (D. Wang), m.wistuba@tu-bs.de (M. P. Wistuba).

Peer review under responsibility of Periodical Offices of Chang'an University.
http://dx.doi.org/10.1016/j.jtte.2017.05.009

Please cite this article in press as: Groenniger, J., et al., Experimental investigation of asphalt mixture containing Linz-Donawitz steel slag, Journal of Traffic and Transportation Engineering (English Edition) (2017), http://dx.doi.org/10.1016/j.jtte.2017.05.009

slag are suitable for asphalt pavement construction and that in most cases they perform better than conventional asphalt mixtures prepared with Gabbro aggregate.

1. Background and scope

1.1. Use of slag in asphalt mixtures

The production process of steel results in a significant amount of slag by-product: approximately 1 ton of slag per 3 tons of stainless steel (Proctor et al., 2000). For Europe, every year nearly 12 million tons of steel slag is produced. The European Union has among its targets an efficient use of natural resources; within this framework, the asphalt industry needs to recycle industrial wastes such as steel slags.

In Germany, the use of slags in asphalt mixtures has a long tradition. A number of research efforts were performed by the German Research Association on blast furnace and steel slags so that the material characteristics of slags are well known (Barišić et al., 2010; Motz and Geiseler, 2001; Yi et al., 2012; Yusof, 2005). At international level, research activities centered their effort addressing the chemical and physical properties of slags used in asphalt mixtures. Xue et al. (2006), Wu et al. (2007) and Wen et al. (2014) evaluated the possibility of using steel slag as aggregate in stone mastic asphalt (SMA) mixtures; mechanochemistry and physical changes of the steel slag were investigated through X-Ray diffraction (XRD) analysis, scanning electron microscopy (SEM), thermogravimetry analysis (TGA) and mercury porosimeter tests. Based on the experimental results, they concluded that steel slags can be used as aggregate since they represent an alternative, cost effective and environmentally friendly aggregate source. The use of steel slag in asphalt mixture was also addressed by Ziari and Khabiri (2007) and Norman et al. (1992) based on Marshall and stability tests according to European Standard EN 12697-34 (CEN, 2012c). Kandhal and Hoffman (1997) and Shatnawi et al. (2008) evaluated the application of steel slag in hot asphalt mixture. Kara et al. (2004) used steel slag to prepare asphalt pavement mixtures for base, binder and wearing courses. According to the authors, the physical properties of steel slag satisfied the standards requirements for asphalt mixture production. Regarding skid resistance of asphalt mixture containing steel slag, Asi (2007) stated that mixtures containing 30% slag have the highest skid number compared to Superpave, SMA, and Marshall mixtures. In addition, a positive effect of steel slag on rutting resistance and fatigue performance was identified (Asi et al., 2007). One of the most critical possible drawbacks associated to the use of steel slag is volume expansion caused by hydration of lime or magnesia components. Hence, high levels of free lime or magnesia may cause cracking of asphalt pavement. The simplest solution to limit this deleterious effect is obtained by aging slags or by accelerating the hydration reaction with water. Alternatively, slag washing can be used, so that minimal volume expansion occurs (Kneller et al., 1994).

1.2. Objective

The objective of the present research is to determine how the use of LD slag in asphalt mixtures affects the functional performance of pavement construction, and specifically, in comparison to conventional mixtures prepared with natural aggregates such as Gabbro. The results of this study and the recommendation for construction process are discussed in this paper.

2. Research approach

The research approach used in this study is based on an extensive experimental program which includes different test methods to assess the mechanical response and the performance of the asphalt mixture composite prepared with different aggregates, steel slag and natural Gabbro. The following properties were evaluated on a set of 8 asphalt mixture variants used in the different structural layers which an asphalt pavement is made of surface, binder and base layers (Asphalt Institute, 2007).

- Resistance to permanent deformation.
- Stiffness.
- Fatigue resistance.
- Resistance to low-temperature cracking.

3. Materials

A total of 8 asphalt mixtures were prepared in the asphalt pavement laboratory. Four different types of mixtures, each with natural Gabbro aggregate and LD slag, were designed using a standard 50/70 asphalt binder and an SBS modified binder with 45/80-65 penetration grade according to European Standard EN 1426 (CEN, 2013a) and ring and ball temperature according to European Standard prEN 1427 (CEN, 2013b).

- MA 11 S (surface layer, mastics asphalt, high filler content).
- SMA 11 S (surface layer, stone mastic asphalt, low filler content).
- AC 16 B S (binder layer, asphalt concrete with a maximum aggregate size of 16 mm).
- AC 22 T S (base layer, asphalt concrete with a maximum aggregate size of 22 mm).

Asphalt mixtures were chosen to ensure that all layers of an asphalt pavement structure (surface layer, binder layer, and base layer) are taken into account. Furthermore, conventional asphalt mixtures with different filler content were used. The corresponding mix design was chosen in accordance with the German Technical Standard: TL Asphalt -StB 07 (FGSV, 2007).

4. Test methods

In order to address the performance characteristics, durability and skid resistance of asphalt with LD slag and with conventional (natural) Gabbro aggregate, asphalt specimens were produced and then tested according to the methods described hereafter. The results obtained from asphalt mixtures prepared with LD slag were then compared to the experimental data measured on asphalt mixtures containing natural Gabbro aggregate. Results and discussion are presented in Section 5.

4.1. *Resistance to permanent deformation*

Deformation resistance was addressed by the following two tests.

(1) Cyclic compression test in accordance with European Standard EN 12697-25 (CEN, 2005) for rolled asphalt SMA 11 S, AC 16 B S and AC 22 T S.
(2) Penetration test in accordance with European Standard EN 12697-25 for mastic asphalt MA 11 S.

In cyclic compression test (Fig. 1(a)) a cylindrical specimen is subjected to repeated pulsed compressive load for 0.2 s, followed by a 1.5 s rest period at a test temperature of 50 °C. During the test, irreversible deformations along the loading direction are recorded for each load cycle. The specimen is positioned centrally under the loading frame to ensure most homogeneous load distribution.

The load curve is characterized by the lower stress level σ_u and the upper stress level σ_o. σ_u ensures contact between specimen and load stamp. The test starts with the application of the first load cycle. A constant upper stress of $\sigma_o = 0.35$ MPa was chosen for testing.

The test ends as soon as 10,000 cycles are reached or when a deformation of 40‰ is exceeded. The basis of evaluation is the creep curve, which shows the evolution of the irreversible permanent deformations in the specimen.

For the evaluation of deformation resistance, the following parameters are used for characterization.

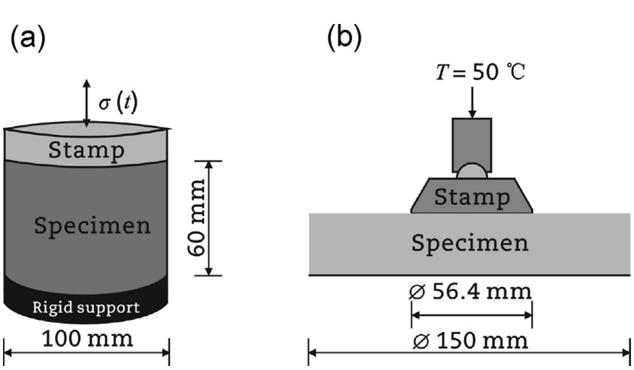

Fig. 1 – Test principle. (a) Cyclic compression test principle. (b) Penetration test principle.

- n_w (–), number of load cycles at the turning point.
- ϵ_w (‰), strain at the turning point.

In the penetration test (Fig. 1(b)) the dynamic penetration (ETdyn) is determined. The specimen is subject to a sinusoidal load for 0.2 s followed by a rest period of 1.5 s. The test ends when 2500 load cycles (including load pulse and rest period) are reached. Penetration depth at end of test is documented. The test temperature was set to 50 °C.

4.2. *Stiffness and fatigue resistance*

Stiffness and fatigue resistance (cracking resistance to repeated loading) are addressed by cyclic indirect tensile test according to the European Standard EN 12697-24 (CEN, 2012a). A sinusoidal load is applied to a cylindrical asphalt specimen via two diametrically opposite load transfer rails. To stabilize the position of the asphalt specimen in the loading frame, a seating load equivalent to a stress of $\sigma_u = 0.035$ MPa is applied, while the maximum stress σ_o is chosen based on elastic horizontal strain ϵ_{el} between 50 and 100 m/m. Tests were carried out in a temperature–frequency sweep mode as shown in Table 1. Resulting parameter is stiffness modulus in function of frequency, represented by isotherm plot and by master curve plot.

Fatigue performance is obtained based on a continuous cyclic loading procedure in the non-linear domain. Stress is varied in a way that initial strains are in a range of 0.05‰–0.30‰ and the number of load cycles until macro cracking (drop in stiffness modulus by 50%) is in the range of 10,000–1,000,000 load cycles on cyclic indirect tensile test were carried out under the conditions specified in Table 2. Resulting parameters are the number of load cycles until macro cracking and the material-specific fatigue function.

4.3. *Resistance to low-temperature cracking*

In order to determine the resistance to low-temperature cracking, prismatic asphalt specimens were subjected to thermal stress restrained specimen tests in accordance with European Standard EN 12697-46 (CEN, 2012b).

Prior to the test, a prismatic specimen having dimensions 40 mm × 40 mm × 160 mm were glued to steel adapters. After a minimum of 48 h glue curing, specimens are installed in the test device. During thermal stress restrained specimen test, the length of the specimen is held constant through a set of linear variable displacement transformer (LVDT), while its temperature is decreased from an initial value of $T = +20$ °C with a constant cooling rate of $\Delta T = -10$ °C/h. A close-loop

Table 1 – Experimental parameters for the determination of stiffness based on cyclic indirect tensile test according to EN 12697-24.

Parameter	Values/response
Test temperature (°C)	+20, +10, 0, −10
Loading frequency (Hz)	0.1, 1, 5, 10
Result	Stiffness modulus $\|E\|$ in MPa and master-curve

Please cite this article in press as: Groenniger, J., et al., Experimental investigation of asphalt mixture containing Linz-Donawitz steel slag, Journal of Traffic and Transportation Engineering (English Edition) (2017), http://dx.doi.org/10.1016/j.jtte.2017.05.009

Table 2 – Experimental parameters for determining the fatigue performance based on cyclic indirect tensile test according to EN 12697-24.

Parameter	Values/response
Test temperature (°C)	+20
Standardized form	10
Result	Number of load cycles until macro crack Fatigue function $N_{Makro} = C_1 \epsilon_{el,\,anf}^{C_2}$ with material specific parameters C_1, C_2

control system keeps the specimen at constant length. Due to the prohibited thermal shrinkage, the specimen is subjected to an increasing (cryogenic) tensile stress. The test ends at a minimum test temperature of $T = -40$ °C or at failure, when the cryogenic stress exceeds the tensile strength of the asphalt mixture, respectively.

The test returns a temperature-dependent function of cryogenic stress σ_{cry} (T) (MPa), a failure stress σ_F (Mpa) and a failure temperature T_F (°C).

5. Results and discussion

5.1. *Resistance to permanent deformation*

Penetration depths observed for mastic asphalt (MA 11 S with LD slag and with natural Gabbro aggregate) are shown in Fig. 2(a). After 2500 load cycles, MA 11 S with LD slag showed much lower penetration depth compared to the MA 11 S with natural Gabbro aggregate. The use of LD slag in mastic asphalt leads to an advantageous deformation resistance compared to mastic asphalt with natural Gabbro aggregate.

Deformation resistance of stone mastic asphalt SMA 11 S (Fig. 2(b)) shows the same tendency as for the mastic asphalt variants. The number of tolerable load cycles until the turning point of the SMA 11 S with LD slag is significantly higher than for the SMA 11 S with natural aggregate Gabbro. The resulting strains are comparable in magnitude. Hence, a trend similar to those observed for MA 11 S is shown by the SMA 11 S when using LD slag.

The deformation resistances in terms of number of load cycles at the turning point for the asphalt mixtures for binder and base courses (AC 16 B S and AC 22 T S with LD slag and with natural Gabbro aggregate, respectively) are shown in Fig. 3. The results indicate an opposite trend compared to the asphalt mixtures for surface layer (MA 11 S and SMA 11 S). The number of tolerable load cycles until the turning point is much lower for mixtures prepared with LD slag; the resulting strains are comparable in magnitude.

Concerning the disadvantageous deformation behavior of the asphalt binder and asphalt base mixtures prepared with LD slag, it has to be noted that similar mix design (same gradation and bitumen content) was used for mixtures containing natural and recycled aggregates. Consequently, LD slag mixtures showed higher air voids contents (up to 3.0 vol%). This is due to a higher asphalt binder demand of LD slag associated with their porous structure. High air voids contents negatively affect stiffness and resistance to permanent deformation.

5.2. *Stiffness and fatigue resistance*

The stiffness of the asphalt surface mixtures (mastic asphalt MA 11 S and stone mastic asphalt SMA 11 S, each with LD slag and natural Gabbro aggregate) is shown in Fig. 4 in terms of modulus E (complex modulus) in function of temperature. The resulting stiffness is for all asphalt surface mixtures at a comparable level, regardless of whether LD slag or natural Gabbro aggregate was used.

The stiffness of the asphalt binder and asphalt base course mixtures (AC 16 B S and AC 22 T S, each with LD slag and natural Gabbro aggregate) are comparable too (not shown). Overall, a minimal decrease in stiffness can be observed for mixture prepared with LD slag. Nevertheless, this is negligible and does not significantly affect the performance of asphalt pavement under traffic loading.

Fatigue resistances of the asphalt surface mixtures (mastic asphalt MA 11 S and stone mastic asphalt SMA 11 S, each with LD slag and natural Gabbro aggregate) are shown as Wöhler curves in Fig. 5. Similar fatigue resistance is shown for mixtures prepared from natural and recycled aggregates (LD slag).

Fatigue resistances of the asphalt binder and asphalt base course variants (AC 16 B S and AC 22 T S, each with LD slag and natural Gabbro aggregate) are shown as Wöhler curves in Fig. 6.

The Wöhler curves of asphalt binder and asphalt base mixtures with LD slag are shifted upwards in an almost parallel manner with respect to those of the mixtures containing natural aggregate. Thus, for the same elastic strain, mixtures with LD slag can sustain a higher number of load cycles before

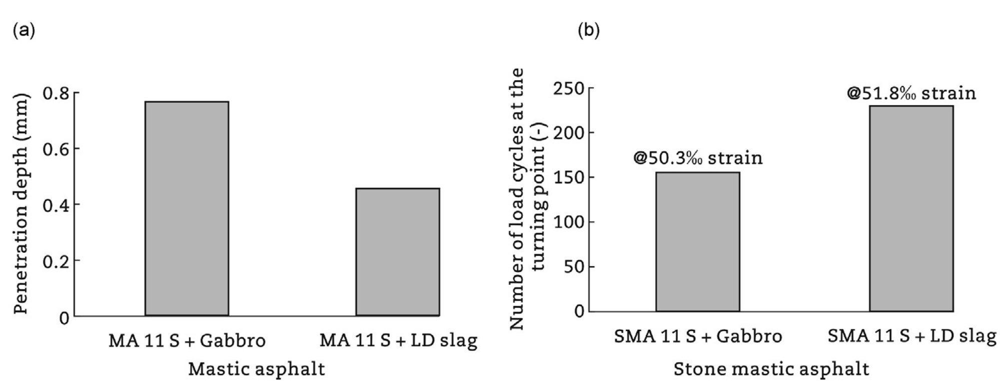

Fig. 2 – Deformation resistance. (a) Mastic asphalt MA 11 S with LD slag and natural Gabbro aggregate. (b) Stone mastic asphalt SMA 11 S with LD slag and natural Gabbro aggregate.

Please cite this article in press as: Groenniger, J., et al., Experimental investigation of asphalt mixture containing Linz-Donawitz steel slag, Journal of Traffic and Transportation Engineering (English Edition) (2017), http://dx.doi.org/10.1016/j.jtte.2017.05.009

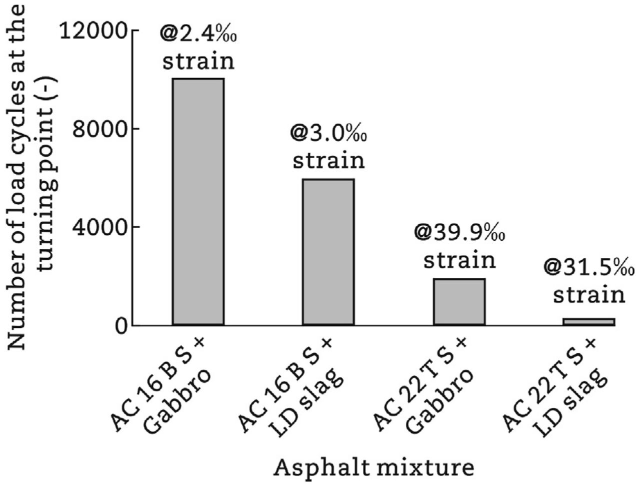

Fig. 3 – Deformation resistance of asphalt binder AC 16 B S and asphalt base course AC 22 T S.

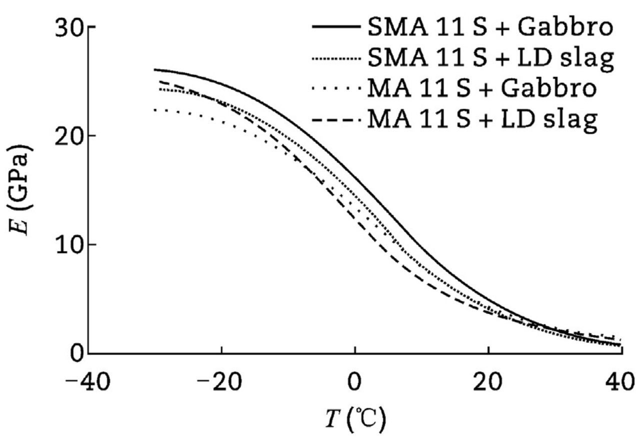

Fig. 4 – Stiffness of mastic asphalt MA 11 S and stone mastic asphalt SMA 11 S.

a macro crack (material failure) appears. Therefore, the experimental results indicate that the use of LD slag in asphalt binder and asphalt base course mixtures leads to a higher fatigue resistance in comparison to mixture designed with natural Gabbro aggregate.

5.3. *Resistance to low-temperature cracking*

The resistances to low-temperature cracking of the asphalt surface mixtures (MA 11 S and SMA 11 S, each with LD slag and natural Gabbro aggregate) were determined based on thermal stress restrained specimen tests. Fig. 7 shows the cryogenic failure stresses (maximum stress until failure) while Fig. 8 presents the corresponding temperatures at failure.

The parameters describing the resistance to low-temperature cracking are comparable for all asphalt surface mixtures prepared with LD slag or natural aggregate. The failure stresses observed are at a high (good) level. This level is typical for commonly used asphalt pavement surface layers in Europe. The failure temperatures are below −20 °C (marked in Fig. 8), and thus on a non-critical level for thermal cracking.

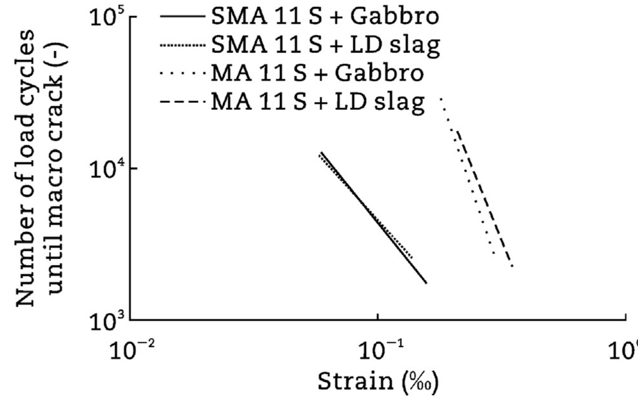

Fig. 5 – Fatigue resistance of mastic asphalt MA 11 S and stone mastic asphalt SMA 11 S.

The resistance to thermal cracking of the asphalt binder and asphalt base course mixtures (AC 16 B S and AC 22 T S, each with LD slag and natural Gabbro aggregate) is shown in Figs. 9 and 10.

The parameters describing the resistance to thermal cracking indicate that the low-temperature behavior of mixtures with LD slag tends to provide relatively poor performance compared to the mixture with natural Gabbro aggregate. The failure stresses are lower and the failure temperatures are higher. However, the level is evaluated as “adequate” for European weather conditions.

6. Summaries and conclusions

In this paper, the fundamental performance properties of different types of asphalt mixtures prepared with 100% LD slag and natural aggregate were investigated. Resistance to permanent deformation, stiffness, fatigue and low-temperature cracking were evaluated based on a comprehensive set of experimental methods. The following conclusions can be drawn.

- The use of LD slag in mastic asphalt leads to an advantageous deformation resistance compared to mastic asphalt with natural Gabbro aggregate. In contrast, asphalt binder and asphalt base course mixtures with LD slag showed a

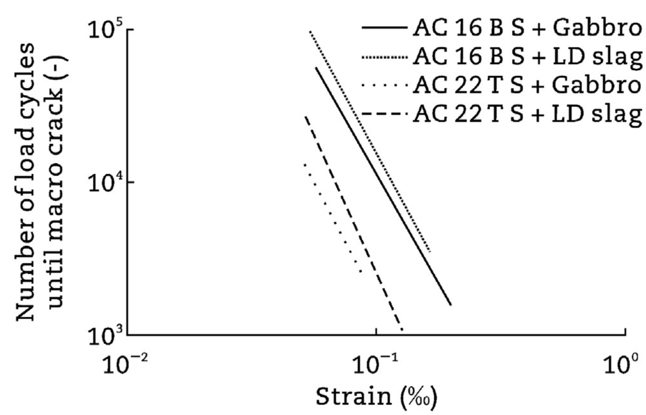

Fig. 6 – Fatigue resistance of asphalt binder AC 16 B S and asphalt base course AC 22 TS.

Please cite this article in press as: Groenniger, J., et al., Experimental investigation of asphalt mixture containing Linz-Donawitz steel slag, Journal of Traffic and Transportation Engineering (English Edition) (2017), http://dx.doi.org/10.1016/j.jtte.2017.05.009

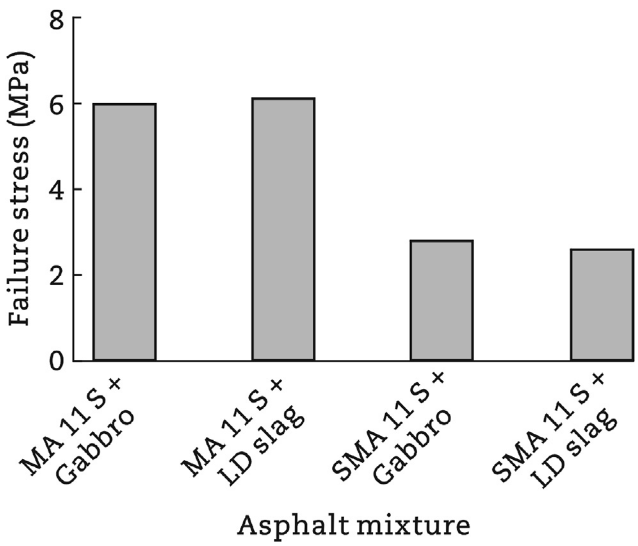

Fig. 7 – Resistance to low-temperature cracking of mastic asphalt MA 11 S and stone mastic asphalt SMA 11 S.

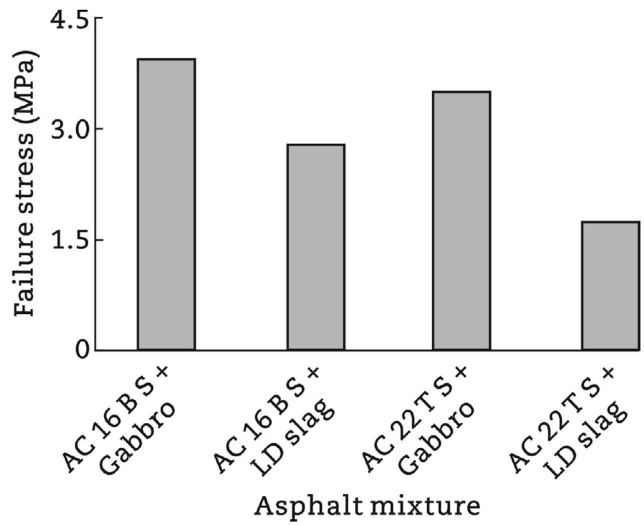

Fig. 9 – Resistance to low-temperature cracking of asphalt binder AC 16 B S and asphalt base course AC 22 T S.

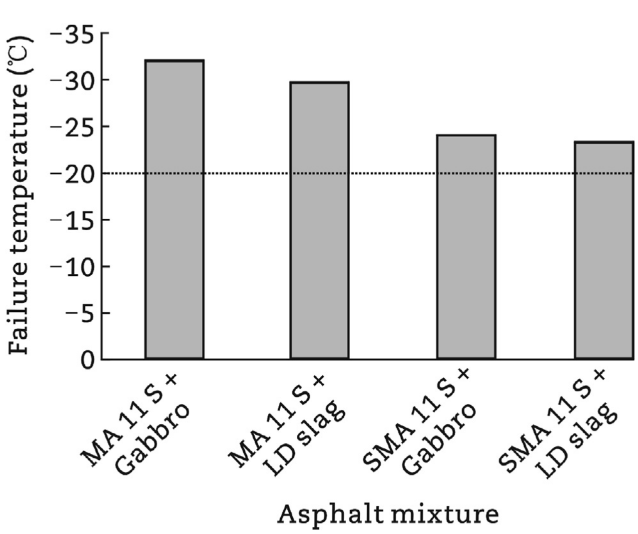

Fig. 8 – Resistance to thermal cracking of mastic asphalt MA 11 S and stone mastic asphalt SMA 11 S.

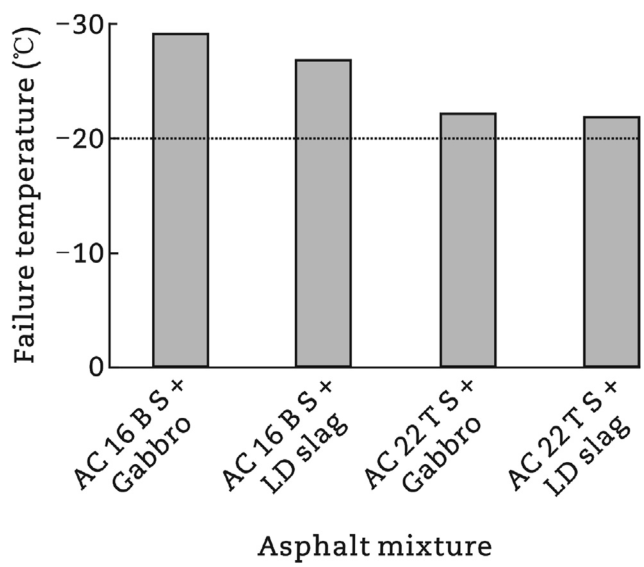

Fig. 10 – Resistance to thermal cracking of asphalt binder AC 16 B S and asphalt base course AC 22 T S.

lower deformation resistance compared to the mixtures with natural Gabbro aggregate. Due to a higher binder need of LD slag, the mixtures with LD slag showed slightly higher air voids contents resulting in a disadvantageous resistance to deformation.

- The stiffness of the asphalt surface, asphalt binder, and asphalt base mixtures are at a comparable level, regardless of whether LD slag or natural Gabbro aggregate was used.
- Fatigue resistances for the asphalt surface mixtures are at a comparable level, regardless of whether LD slag or natural Gabbro aggregate was used. The use of LD slag in asphalt binder and asphalt base course leads to a higher fatigue resistance in comparison to mixtures with natural Gabbro aggregate.
- The level of resistance to thermal cracking is comparable for all asphalt mixtures, regardless of whether LD slag or natural aggregate Gabbro was used. The level is evaluated as "adequate" for European weather conditions.

Overall, the experimental results and the analysis conducted in the present investigation indicate that asphalt mixtures prepared with LD slag are suitable for asphalt pavement construction and that in most cases they perform as good as or even better than conventional asphalt mixtures prepared with natural aggregate.

REFERENCES

Asi, I.M., 2007. Evaluating skid resistance of different asphalt concrete mixes. Building and Environment 42 (1), 325–329.

Asi, I.M., Qasrawi, H.Y., Shalabi, F.I., 2007. Use of steel slag aggregate in asphalt concrete mixes. Canadian Journal of Civil Engineering 34 (8), 902–911.

Asphalt Institute, 2007. The Asphalt Handbook, seventh ed. Asphalt Institute, Lexington.

Barišić, I., Dimter, S., Natinger, I., 2010. Possibilities of application of slag in road construction. Technical Gazette 17 (4), 523–528.

European Committee for Standardization (CEN), 2012a. Bituminous Mixtures-Test Methods for Hot Mix Asphalt-Part 24: Resistance to Fatigue. European Standard EN 12697-24. CEN, Brussels.

European Committee for Standardization (CEN), 2012b. Bituminous Mixtures-Test Methods for Hot Mix Asphalt – Part 46: Low Temperature Cracking and Properties by Uniaxial Tension Tests. European Standard EN 12697-46. CEN, Brussels.

European Committee for Standardization (CEN), 2012c. Bituminous Mixtures-Test Methods for Hot Mix Asphalt-Part 34: Marshall Test. European Standard EN 12697-34. CEN, Brussels.

European Committee for Standardization (CEN), 2013a. Bitumen and Bituminous Binders-Determination of Needle Penetration. European Standard EN 1426. CEN, Brussels.

European Committee for Standardization (CEN), 2013b. Bitumen and Bituminous Binders-Determination of the Softening Point-Ring and Ball Method. European Standard prEN 1427. CEN, Brussels.

European Committee for Standardization (CEN), 2005. Bituminous Mixtures-Test Methods for Hot Mix Asphalt-Part 25: Cyclic Compression Test. European Standard EN 12697-25. CEN, Brussels.

Forschungsgesellschaft für Straßen- and Verkehrswesen (FGSV), 2007. Technische Lieferbedingungen für Asphaltmischgut für den Bau von Verkehrsflächenbefestigungen (TL Asphalt-StB 07). FGSV 797. FGSV, Köln.

Kandhal, P., Hoffman, G., 1997. Evaluation of steel slag fine aggregate in hot-mix asphalt mixtures. Transportation Research Record 1583, 28–36.

Kara, M., Günay, E., Kavakli, B., et al., 2004. The use of steel slag in asphaltic mixture. Key Engineering Materials 264, 2493–2496.

Kneller, W.A., Gupta, J., Borkowski, M.L., et al., 1994. Determination of original free lime content of weathered iron and steel slags by thermogravimetric analysis. Transportation Research Record 1434, 17–22.

Motz, H., Geiseler, J., 2001. Products of steel slags an opportunity to save natural resources. Waste Management 21 (3), 285–293.

Norman, A., Joseph, C., Papagiannakis, T., et al., 1992. Use of steel slag in asphaltic concrete, 1147. ASTM Special Technical Publication 1992, 3–18.

Proctor, D.M., Fehling, K.A., Shay, E.C., et al., 2000. Physical and chemical characteristics of blast furnace, basic oxygen furnace, and electric arc furnace steel industry slags. Environmental Science and Technology 34 (8), 1576–1582.

Shatnawi, A.S., Abdel-Jaber, M.T.S., Abdel-Jaber, M.E.S., et al., 2008. Effect of Jordanian steel blast furnace slag on asphalt concrete hot mixes. Jordan Journal of Civil Engineering 2 (3), 197–207.

Wen, H., Wu, E., Bhusal, S., 2014. Evaluation of Steel Slag as Hot Mix Asphalt Aggregate. Washington Center for Asphalt Technology (WCAT), Washington State University, Pullman.

Wu, S., Xue, Y., Ye, Q., et al., 2007. Utilization of steel slag as aggregates for stone mastic asphalt (SMA) mixtures. Building and Environment 42 (7), 2580–2585.

Xue, Y., Wu, S., Hou, H., et al., 2006. Experimental investigation of basic oxygen furnace slag used as aggregate in asphalt mixture. Journal of Hazardous Materials 138 (2), 261–268.

Yi, H., Xu, G., Cheng, H., et al., 2012. An overview of utilization of steel slag. Procedia Environmental Sciences 16, 791–801.

Yusof, M.A.W., 2005. Investigating the Potential for Incorporating Tin Slag in Road Pavements (PhD thesis). University of Nottingham, Nottingham.

Ziari, H., Khabiri, M.M., 2007. Preventive maintenance of flexible pavement and mechanical properties of steel slag asphalt. Journal of Environmental Engineering and Landscape Management 15 (3), 188–192.

Jens Groenniger

Dipl.-Wirtsch.-Ing. Assistant researcher

Since 2015 – Deputy laboratory manager

Since April 2007 – Research associate at ISBS of Technische Universität Braunschweig

Since April 2007 – PhD student, at ISBS of Technische Universität Braunschweig

2006 – Diploma degree in industrial/civil engineering, Technische Universität Braunschweig, Germany

Research interests

Adhesion behavior between bitumen and stone

Possibilities of reuse of excavated asphalt at a high level of the added value

Influence of the asphalt mortar to the essential properties of asphalt

Application of thermography for the non-destructive testing of pavements

https://www.tu-braunschweig.de/isbs/mitarbeiter/wissenschaftliche/groenniger

Augusto Cannone Falchetto

Assistant Professor

Since July 2017 – Assistant Professor at TU Braunschweig

2013–2017 – Research associate at ISBS

2008–2013 – Research assistant in the Department of Civil Engineering at the University of Minnesota, USA

2013 – PhD in civil engineering (minor statistics), University of Minnesota, USA

2011 – PhD in civil engineering, University of Parma, Italy

2010 – MS in civil engineering, University of Minnesota, USA

2005 – Master in infrastructure design, University of Padova, Italy

2004 – Laurea, University of Padova, Italy

Please cite this article in press as: Groenniger, J., et al., Experimental investigation of asphalt mixture containing Linz-Donawitz steel slag, Journal of Traffic and Transportation Engineering (English Edition) (2017), http://dx.doi.org/10.1016/j.jtte.2017.05.009

Research interests

Characterization and modeling of asphalt materials at low-temperatures

Asphalt materials recycling

Size effect and scaling of quasibrittle materials

https://www.tu-braunschweig.de/isbs/mitarbeiter/wissenschaftliche/cannone

Ivan Isailović

MSc Assistant researcher

Since April 2012 – Research assistant at the ISBS

2011 – MSc in the degree program "road, train and airport engineering", University of Belgrade

Research interests

Advancement of approaching material properties using static and cyclic-dynamic laboratory tests

https://www.tu-braunschweig.de/isbs/mitarbeiter/wissenschaftliche/isailovic

Di Wang

MSc – Assistant researcher

Since May 2015 – PhD student, at ISBS of Technische Universität Braunschweig

2011–2014 – Research associate in the School of Highway at Chang'an University, China

2014 – MSc in civil engineering, Chang'an University, China

2010 – Bachelor in pavement engineering, School of Highway, Chang'an University, China

Research interests

Characterization and modeling of asphalt materials at low-temperatures

Asphalt materials recycling

Diffusion process of rejuvenators and fresh binder in the aged binder contained in reclaimed asphalt pavement materials

https://www.tu-braunschweig.de/isbs/mitarbeiter/wissenschaftliche/di

Michael P. Wistuba

Univ.-Prof. Dipl.-Ing. Dr.techn. Head and director of the ISBS

Since March 2008 – Head of the Braunschweig Pavement Engineering Centre, Technische Universität Braunschweig

April 2011–April 2013 – Dean for studies in civil engineering, TU Braunschweig

2002–2008 – Deputy head of the Christian Doppler Laboratory for Performance-based Optimization of Flexible Road Pavements, Technische Universität Wien

2002–2003 – Scientific project manager ETH Lausanne (Switzerland)

2002 – PhD, Technische Universität Wien

1998–2008 – University assistant at the Institute for Road Construction and Road Maintenance (Prof. J. Litzka, Prof. R. Blab), Technische Universität Wien

1998 – Diploma degree in civil engineering, Technische Universität Wien

Research interests

Technical testing to address the performance properties of road building materials

Composition of mixture of bituminous bound building materials

Design of highway and airport pavements

Development of concepts to achieve durability

https://www.tu-braunschweig.de/isbs/mitarbeiter/leitung/wistuba

Please cite this article in press as: Groenniger, J., et al., Experimental investigation of asphalt mixture containing Linz-Donawitz steel slag, Journal of Traffic and Transportation Engineering (English Edition) (2017), http://dx.doi.org/10.1016/j.jtte.2017.05.009