

## COMPARISON OF ASPHALT CONCRETE PERFORMANCE USING CONVENTIONAL AND UNCONVENTIONAL AGGREGATE

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### ABSTRACT

*Annually up to 200 thousand tons of steel slag, a non metallic co-product of iron and steel production, are produced in Latvia. However, it has not been extensively used in asphalt pavement despite of its high performance characteristics. Dolomite sand waste, which is co-product of crushed dolomite production, is another widely available polydisperse waste material in Latvia. Its quantity has reached millions of tons and is rapidly increasing. This huge quantity of technological waste needs to be recycled with maximum efficiency.*

*The study investigates the use of dolomite sand waste as filler or/and sand material plus steel slag as fine and coarse aggregate for the design of high performance asphalt concrete. Both environmental and economic factors contribute to the growing need for the use of these materials in asphalt concrete pavements. This is particularly important for Latvia, where local crushed dolomite and sandstone does not fulfill the requirements for mineral aggregate in high and medium intensity asphalt pavements roads.*

*Various combinations of steel slag, dolomite sand waste and conventional aggregates were used to develop AC 11 asphalt concrete mixtures. The mix properties tests include resistance to permanent deformations (wheel tracking test, dynamic creep test) and fatigue resistance. Laboratory test results showed that asphalt concrete mixtures containing steel slag and local limestone in coarse portion and dolomite sand waste in sand and filler portions had high resistance to plastic deformations and good resistance to fatigue failure.*

**Key words:** co-product, steel slag, dolomite sand waste, permanent deformations, fatigue resistance

### INTRODUCTION

Asphalt concrete pavements are constructed of bituminous and polydisperse granular materials. Regardless of the thickness or type of asphalt pavement, the load is transmitted through the aggregate, the bitumen serving as a cementing agent to bind the aggregate in proper position to transmit the applied wheel loads to underlying layers where the load is finally dissipated (Huang, 1993, Mallick and El-Korchi, 2009).

Local crushed dolomite and sandstone aggregate lack the desirable qualities for asphalt concrete mix design (Skinskas et al. 2010). In the meantime, as natural supplies of high quality granular materials used in highways have become less abundant, the highway engineer is faced with the challenge of finding alternative materials to meet the requirements for these materials (Yilmaz and Sutas, 2012). Some of these alternatives are fly ash, coal dust, hydrated lime, steel slag etc. (Kandhal and Hoffman, 1997). The co-products (slag) of iron and steel production have been used commercially since 19th century (Euroslag, 2006). In the EU and North America steel slag is used in: bituminous bound materials; pipe bedding; hydraulically bound mixtures for subbase and base; unbound mixtures for subbase; capping; embankments and fill construction; clinker manufacture and fertilizer and soil improvement agent (Gintalas 2010,

Xirouchakis et al. 2011). However, in Latvia, for commercial road construction purposes, it has been used only for unbound mixtures.

The research has shown that production of asphalt mixtures with high performance characteristics is possible by using steel slag aggregate (Pasetto et al. 2011). However, the studies have also indicated that, because of the high angularity and texture of the particles, the asphalt often has poor workability (Haryanto et al. 2007). Therefore, the application of slag may have more potential in combination with conventional aggregates (Bagampadde et al. 1999).

The second most widespread co-product in Latvia is the dolomite waste sand. It has been accumulating in quarries for many years and currently its quantity has reached several million tons. Previously it has been used in agriculture as the lime substitute for soil treatment and in the building industry as the quartz sand equivalent. Currently researchers in Latvia also offer to utilize the dolomite sand waste in the concrete production (Korjakins et al. 2008). However, the research on the perspective use of dolomite waste sand in the production of asphalt has received relatively little attention. For example, this material could be used to fully or partially replace the fine and filler portions.

The goal of this study is to develop asphalt mixtures with high performance properties using various combinations of BOF steel slag, dolomite sand

waste, crushed quartz sand crushed dolomite aggregates and to compare the results with the reference asphalt mixture, produced with conventional aggregates. The mix properties tests include resistance to permanent deformations (wheel tracking test, dynamic creep test) and fatigue resistance.

## MATERIALS

The basic materials used in this study are fractionated steel slag, crushed dolomite aggregate; dolomite sand waste, crushed quartz sand, unmodified bitumen B70/100 and SBS modified bitumen PMB 45/80-55. Steel slag was obtained from JSC Liepajas metalurģs (Latvia), dolomite sand waste from Plavinu DM Ltd (Latvia), crushed quartz sand from Jauncerpji Ltd. (Latvia) and crushed dolomite aggregate from AB Dolomitas (Lithuania), 70-100 penetration bitumen from PC Orlen (Lithuania) and SBS modified bitumen from Grupa LOTOS S.A (Poland). Conventional aggregate and unmodified and modified bitumen are used extensively for local mixes.

### Properties of dolomite sand waste

The Latvian law classifies steel slag and dolomite sand waste as non-hazardous solid materials (91/689 EEK). Chemical analysis of dolomite sand is shown in Table 1. There is no evidence of clay minerals being present in dolomite sand. The X-ray diffraction has been used to obtain mineralogical composition of the investigated dolomite waste (Korjakins et al. 2008). The main constituents of waste dolomite are  $\text{CaCO}_3$ - $\text{MgCO}_3$ , which account for more than 92% of the composition.

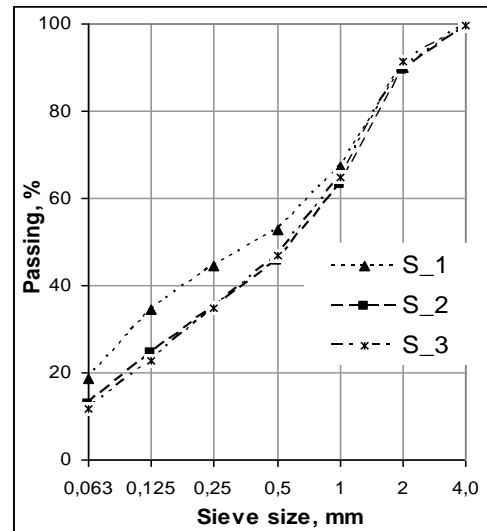
**Table 1**

Chemical properties of waste materials

Steel slag		Dolomite waste sand	
Oxide	Content, %	Oxide	Content, %
CaO	30.6	CaO	31.0
MgO	18.9	MgO	17.0
SiO <sub>2</sub>	19.9	SiO <sub>2</sub>	2.5
MnO	6.3	Na <sub>2</sub> O	0.82
Al <sub>2</sub> O <sub>3</sub>	5.0	Al <sub>2</sub> O <sub>3</sub>	0.64
TiO <sub>2</sub>	0.52	K <sub>2</sub> O	0.76
FeO	16.3	Fe <sub>2</sub> O <sub>3</sub>	0.34

This material contains more than 10% of fines (below 0.063mm) and therefore it has to be tested for properties of mineral filler (Fig.1). The fine particles of this material are part of the mixture mineral carcass and contribute to obtain a dense structure by filling the voids between coarse

aggregate particles. The mineral filler that is in this material, however, provides more contact points between fine and coarse aggregate thus improving the mechanical properties of the mixture. Another function of the mineral filler is to increase the bitumen viscosity and improve the properties of the binder



**Figure 1.** Particle size distribution of dolomite waste sand

**Table 2**

Physical and mechanical characteristics of dolomite sand

Physical and mechanical properties	Standard	Dolomite waste sand	Dolomite filler	Crushed quartz sand
Sand equivalent test, %	LVS EN 933-8	60	-	91
Flow coefficient (ECS)	LVS EN 933-6	33	-	35
Water absorption, %	LVS EN 1097-6	2.0	2.7	5.4
Grain density, Mg/m <sup>3</sup>	LVS EN 1097-6	28.0	2.75	2.80
Fine content, %	LVS EN 933-1	12-19	78-88	0.9
Methylene blue test (MB), g/kg	LVS EN 933-9	0.5	-	0.5
Carbonate content, %	LVS EN 196-21	> 90	> 90	-
Rigden air voids, %	LVS EN 1097-4	28-30	28-30	-
Delta ring and ball test, °C	LVS EN 13179-1	8-25	8-25	-

Table 2 contains test results of conventional sand and dolomite filler for comparison of the properties of sand waste's fine portion and filler portion respectively. The properties of both of these

fractions correspond to high quality requirements. Dolomite waste sand test results present excellent angularity with an average flow coefficient of 33. Test results show that the fines quality is high – the material has low methylene blue (MB) value – 0.5 high carbonate content – more than 90%, excellent Rigden air voids and Delta ring and ball tests results

#### Properties of steel slag aggregate

The properties of BOF steel slag correspond to the highest category of LVE EN 13043 standard. However, because of high abrasivity of this material, the proportion of it for wearing courses according to Latvian Road Specifications 2012 has been restricted to 20 percent. The test results of steel slag main properties show very low flakiness index – 2, excellent mechanical strength with average LA value of 19, high frost resistance with average MS value of 3, low fines content – 0.5% and slag expansion tests, showed that the expected swelling should be negligible ( Table 3).

**Table 3**  
Physical and mechanical characteristics of steel slag aggregate

Physical and mechanical properties	Related standard	Steel slag aggregate	Crushed dolomite aggregate
Los Angeles (LA) coefficient, %	LVS EN 1097-2	19	22
Resistance to wear. Nordic test (AN), %	LVS EN 1097-9	14.4	15.7
Flakiness Index (FI), %	LVS EN 933-3	2	12
Water absorption, %	LVS EN 1097-6	2.4	2.7
Grain density, Mg/m <sup>3</sup>	LVS EN 1097-6	3.25	2.80
Fine content, %	LVS EN 933-1	0.5	0.9
Freeze/thawing (MS), %	LVS EN 1367-2	3	9
Expansion, %	LVS EN 1744-1	2	-

#### Bitumen tests

Unmodified bitumen BND 60/90 (category defined in accordance to Russian specifications) and SBS polymer modified bitumen was used for the testing. All the test results of the bitumen BND 60/90 and PMB are shown in Table 4 and 5.

#### MIX DESIGN

Dense graded AC mixtures have been designed by using conventional and unconventional raw materials. The Marshall mix design procedure was used for the determination of the optimal bitumen content for the reference mixture, considering the

mixture test results for Marshall stability and flow, as well as the volumetric values: air voids (V), voids in mineral aggregate (VMA) and voids filled with bitumen (VFB) (Roberts *et al.* 2002). Test specimens for the Marshall Test were prepared in the laboratory by impact compactor according to LVS EN 12697-30 with 2×50 blows of the hammer at 140°C temperature. The optimal bitumen content was determined by optimisation of the volumetric characteristics. Variation of bitumen content even with having similar grading curves can result in high hygroscopicity of dolomite waste material, differences in aggregate bulk density and high bitumen absorption of BOF steel slag material (Sivilevičius *et al.* 2008; Sivilevičius *et al.* 2011 ).

**Table 4**  
Typical characteristics of the bitumens

Parameter	BND 60/90	PMB 10/40-65	PMB 45/80-55	PMB 25/55-60	Standard
Penetration at 25°C, dmm	65.0	40.0	50.0	34.0	LVS EN 1426
Softening point, °C	50.4	65	58.4	63.5	LVS EN 1427
Fraas temperature °C	-25	-17	-20	-23	LVS EN 12593
Kinematic viscosity, mm <sup>2</sup> /s	607	239	1203	171	LVS EN 12595
Dynamic viscosity, Pa·s	340	416	1074	302	LVS EN 12596
Elastic recovery, %	-	87	88	89	LVS EN 13398

**Table 5**  
Ageing characteristics of bitumen under the influence of heat and air (RTFOT method)

Parameter	BND 60/90	PMB 10/40-65	PMB 45/80-55	PMB 25/55-60	Standard
Loss in mass, %	0.1	0.01	0.02	0.02	LVS EN 12607-1
Retained penetration, %	70.8	75	69.7	79.4	LVS EN 1426
Increase of a softening point, °C	6.4	7.2	5.9	6.2	LVS EN 1427
Fraas breaking point after aging, °C	-20.0	-15	-18	-19	LVS EN 12593

## PERFORMANCE EVALUATION

Three different groups of mixtures were analyzed:

- Two reference mixtures without co-products (with conventional and SBS bitumen), which were used as a control;
- Mixtures containing only BOF slag and dolomite waste sand;
- Combination of conventional and unconventional materials.

Performance tests are time-consuming and the number of combinations is very large; therefore in the first phase the different mixtures were evaluated with axial and triaxial loads. The combinations that have the highest deformation resistance will be tested for rut resistance and fatigue (see Fig. 2).

### Uniaxial and triaxial test

For this test the standard LVS EN 12697-25 was followed. The Uniaxial and Triaxial Cyclic Compression test is performed using specimens with 101.7 mm diameter and  $63.5 \pm 2.5$  mm height. The laboratory specimens were compacted using the Marshall Impact compactor. The applied load had a block - pulse shape with 1sec of loading time and 1sec of rest time. The test duration was 3600 cycles and the test temperature was 40 °C for uniaxial and 50 °C for triaxial loading. The maximum axial stress for uniaxial loading was 100 kPa. The maximum axial stress for triaxial loading

was 200 kPa and 100kPa confining pressure. Figure 3 and 4 shows the uniaxial and triaxial test results. In order to reduce the number of tests, the following tests will be performed for the combinations with unmodified binder BND 60/90 and PMB 45/80-55. The combinations with PMB 45/80-55 binder showed a slightly higher resistance to deformations. In the following stages of the research the rutting resistance and fatigue performance will be evaluated for other combinations as well.

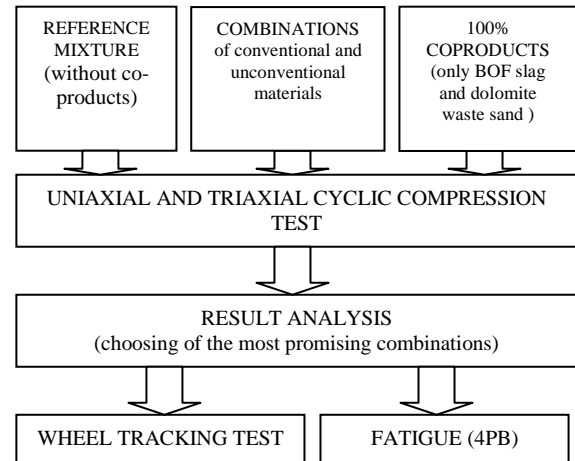


Figure 2. Performance evaluation plan

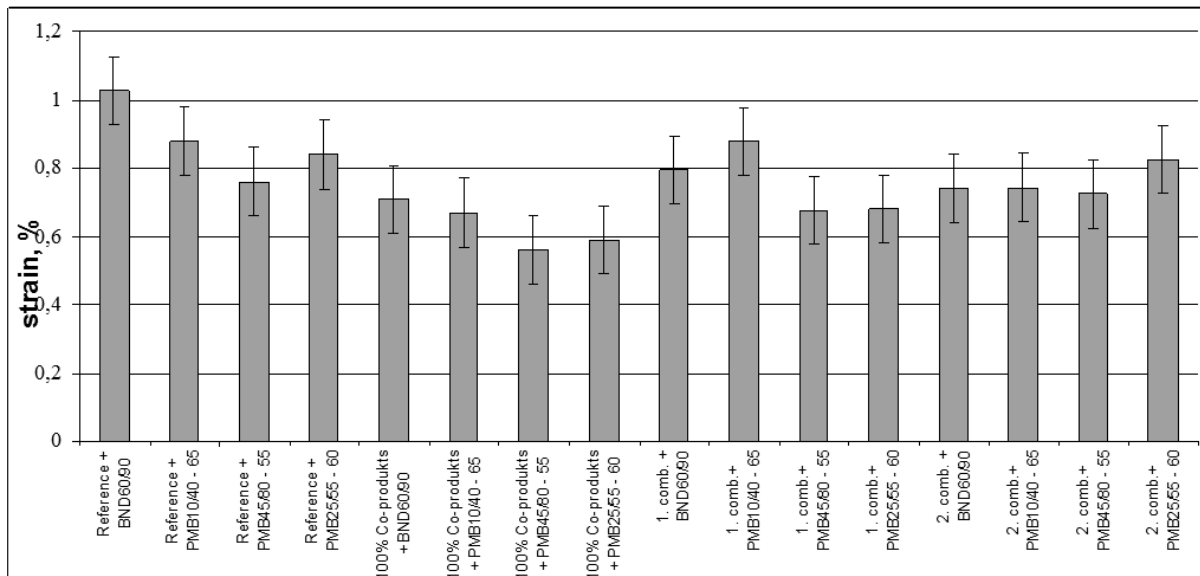
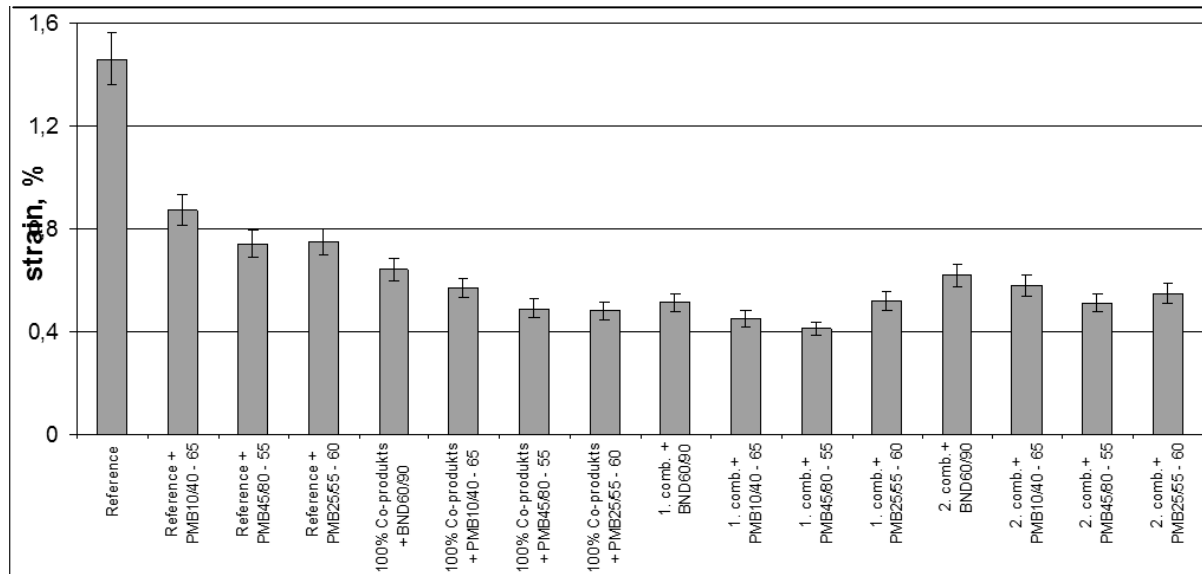


Figure 3. Uniaxial compression test results (Uniaxial compression test, 40°C, 100kPa, 3600 cycles)



**Figure 4.** Triaxial test results (Triaxial test, 50°C, 200/100kPa, 1000 cycles)

### Wheel tracking test

To perform a rut resistance test, a wheel tracking apparatus is used to simulate the effect of traffic and to measure the deformation susceptibility of asphalt concrete samples. Tests were performed according to standard LVS EN 12697-22 method B (wheel tracking test with small size device suspended in the air). This test method is designed to repeat the stress conditions observed in the field and therefore can be categorized as simulative. The asphalt mixture resistance to permanent deformation is assessed by the depth of the track and its increments caused by repetitive cycles (26.5 cycles per minute) under a constant temperature of 60°C. The rut depths are monitored by means of two linear variable displacement transducers (LVDTs), which measure the vertical displacements of each of the two wheel axles independently as rutting progresses. Figure 5 provides a summary of rut resistance properties of the test specimens.

The obtained results demonstrate that the largest rut depth appear for the reference mixture with unmodified bitumen. The results for the reference mixture with SBS modified bitumen are only slightly better. The asphalt concrete mixture which was produced entirely from co-products shows a high resistance to permanent deformations, having an average rut depth value of 1.54 mm and wheel tracking slope of 0.12 mm/1000 cycles. The mixture with a combination of the co-product and

conventional aggregate had somewhat worse test results.

### Fatigue

To determine the fatigue life of the prepared asphalt concrete mixes, a four point bending fatigue test was conducted. The test was run at 20°C, 30Hz (according to LVS EN 12697-24) at 190  $\mu\text{m/m}$  strain level. The beams were compacted in the laboratory by using roller compactor. They were sawn to the required dimensions of 50mm wide, 50mm high and 400mm long. The failure criterion used in the study is the traditional 50% reduction in initial stiffness. The stiffness reduction curves are shown in Figure 6. The obtained results indicate that the mixture with BOF steel slag and dolomite sand waste (100% co-product) showed less resistance to fatigue, compared to the results for the mixture made with conventional aggregates and combined mixture. The mix designs that include exclusively dolomite aggregates as well as the combination of dolomite and slag in a coarse portion plus waste sand in fine aggregate portion exhibit slightly higher fatigue life compared to other combinations. The fatigue life exceeded 500 thousand cycles for all the combinations with the exception of 100 percent by-product mixtures made with BND 60/90 bitumen. However, to verify the findings more extensive laboratory research is needed – this will allow to determine the relationship between tensile strain at the bottom of the beam and the number of load applications before cracking.

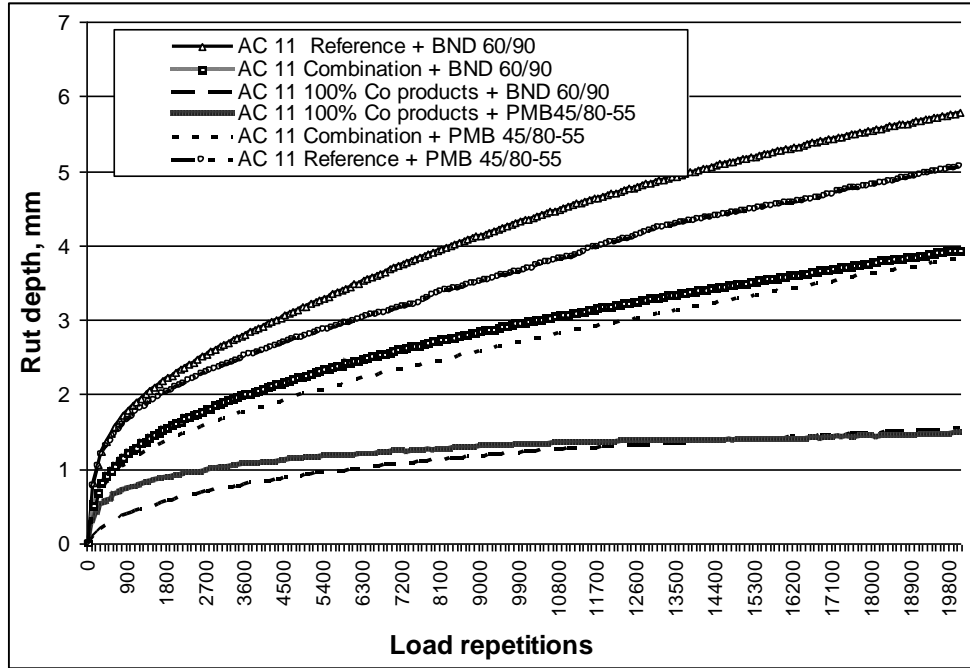


Figure 5. Wheel tracking test results

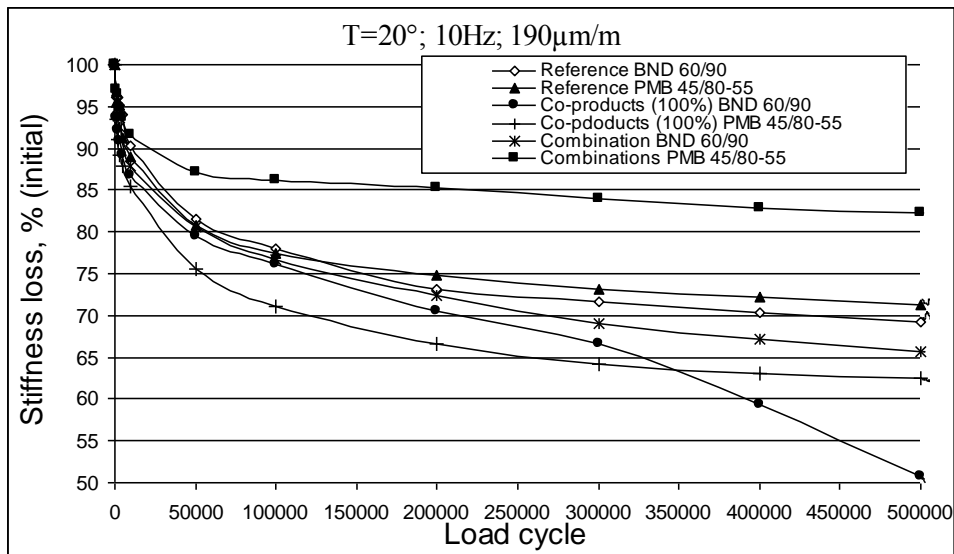


Figure 6. Fatigue test results – stiffness reduction curves

## CONCLUSIONS

Physical and mechanical properties of steel slag aggregates and dolomite sand waste are comparable with the characteristics of conventional natural aggregate usually used in transportation infrastructure.

The results of wheel tracking test and cyclic compression show that mixtures with a high deformation resistance were prepared in the laboratory using two types of co-products.

The analysis of fatigue resistance results show that the mixtures made with steel slag and local

limestone in a coarse portion plus dolomite sand waste in sand and filler portions exhibit a slightly higher fatigue resistance than the conventional mixtures. However, the mixture from 100% steel slag and dolomite waste sand show less resistance to fatigue. To verify the findings more extensive laboratory research is needed – this will allow determining the relationship between tensile strain at the bottom of the beam and the number of load applications before cracking.

## ACKNOWLEDGEMENT

This work has been supported by the European Regional Development Fund (ERDF) activity No.2.1.1.1. „Atbalsts zinātnei un pētniecībai”

(support for the science and research) within the project:No.2010/0254/2DP/2.1.1.1.0/10/APIA/VIA A/015.

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