DEVELOPMENT OF SKID RESISTANT HOT ASPHALT MIXTURES BY BLENDING AGGREGATES FROM DIFFERENT SOURCES

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ABSTRACT

The production of HMA in Israel relies on the Basalt & Dolomite aggregates. The Israeli specifications require exclusive usage of Basalt aggregate for the wearing course, in major highways owing to its superior polishing resistance (PR). Extensive usage of Basalt aggregate caused a shortage, resulting in prices rises and projects delays. The Israeli National Roads Company (INRC) initiated research to test the possibilities of partially replacing some of the Basalt with Dolomite, while still maintaining proper skid resistance (SR).

The research phases were:

1. Literature survey indicating that controlled blending of high and low PR aggregates is an accepted procedure among road authorities internationally.
2. Extensive laboratory tests of PR (mainly PSV), with varied combinations of Basalt and Dolomite mixtures, establishing the feasibility of reducing the percentage of Basalt in the HMA by 40%.
3. Constructing a four kilometres test section with various HMA mixtures; composed of Basalt, Dolomite and controlled Basalt-Dolomite mixtures (black&white, "ZEBRA" appearance). The "Zebra", Z-AC mixture met the acceptance specification requirements.
4. Field performance monitoring proving that the SR of the Z- AC mixtures was superior to the Dolomite's and close to Basalt's.

Based on these findings, the Z- AC mixtures were introduced to the INRC's specifications and design guidelines.

INTRODUCTION

Background- Shortage of basalt aggregates in Israel's Paving Market

The demand for high quality basaltic aggregate has been growing in Israel’s highway paving market for the last ten years. Increased consumption is due to the ability of the basaltic aggregate’s to provide proper Skid Resistance (SR) for Asphalt Concrete (AC) mixtures. The basalt aggregate SR superiority over the other common aggregate types in Israel has been demonstrated in an 8 years strategic research conducted by MAATZ the predecessor of the Israeli National Roads Company (INRC) in the 1970's [Ref. 1]. This superiority was demonstrated both in laboratory using Polishing Resistance (PR) PSV tests and in an actual field test sections. The basalt aggregate was compared with some other aggregate types abundant in Israel, mainly Dolomite. The annual demand in the Israeli paving market, for high quality basaltic aggregate is currently about 800,000 metric tonnes. The current limited production capacity in Israel causes difficulties in supplying the demands [Ref. 2].

In order to resolve the situation, the INRC has initiated several research projects which were aimed to develop AC mixtures that will improve the efficiency of the utilization of the basaltic aggregate resources, while preserving and maintaining the quality of the AC mixtures with a satisfactory skid resistance (SR) values. One of these projects is presented in this article.

Goals of the Research

The main goal of the research were to examine the ability to reduce the amount of basaltic aggregate in AC mixtures for wearing courses, while maintaining proper SR values. Reducing the amount of basaltic aggregate to an optimal level may improve the utilization of the high quality depleting resource, thus improving the economic feasibility of the application of the skid resistant wearing courses' AC mixtures.

R&D PROJECT APPLICATION PHASES

General

The research has been conducted in the following phases:

1. Literature survey.
2. Extensive laboratory tests of PR (mainly PSV)
3. Construction of a four kilometres test section with various HMA mixtures; composed of Basalt, Dolomite and controlled Basalt-Dolomite mixtures
4. Field performance monitoring of the test section
5. Assimilating the successful conclusions of the research in INRC's specifications and design guidelines

The research phases are described below

Highlights from the literature survey

According to the literature [Ref. 1 and ref. 8-17], it was found that diluting the amount of highly polishing-resistant aggregate out of the overall aggregate mix, even in AC mixtures that required controlled and high SR values, is an accepted procedure that is routinely applied according to well established specifications and careful design guidelines, internationally. The literature survey revealed that, when blending aggregates from different mineralogical sources in AC mixtures is applied, care and attention must be paid to several issues:

1. It is possible to dilute the content of highly polishing-resistant aggregates down to a minimum level of 50% of the total coarse aggregate contents (retained on 4.75 mm [4] sieve) without impairing the PR performance of the asphalt mixtures.
2. PR laboratory tests values of the blended mixture must conform fully to specifications requirements. These tests must be followed by a monitoring plan of AC-mix plant production, field construction and field service performance. Only after successful results in these stages routine production may be conducted.
3. Blending of aggregates with specific gravity differences (G) greater than 0.3 requires designing of the blending based on volume ratios.
4. Care must be taken to conduct rigorous mix design procedures and acceptance tests, particularly for the aggregate fractions in which blending are carried out.
5. It is necessary to verify the ability of the asphalt mixing plant to supply the flow of aggregate, in the planned proportions, in a precise and controlled manner.

Aggregate dilution feasibility and preliminary Laboratory tests

At the initial feasibility laboratory testing stages, polished stone value (PSV) tests were conducted in order to verify that blending aggregates from different mineralogical sources is possible without sacrificing the PR specification requirements. Basalt, dolomite and limestone/dolomite aggregates were sampled from various representative Israeli quarries. Aggregate mixtures were prepared with varying proportions of basalt content, in increments of 25%. These samples were tested for PSV following BS-112 Part 114 test procedures (Method for determination of the polished-stone value (PSV)). The results of the feasibility test are presented in Figure 1. The tests pointed out that weight proportions of 50% - 60% basalt content out of total coarse aggregate, is sufficient to provide an aggregate mix that meets the target value of 48 (PSV coefficient), that is required according to INRC's new general specifications [Ref. 3].

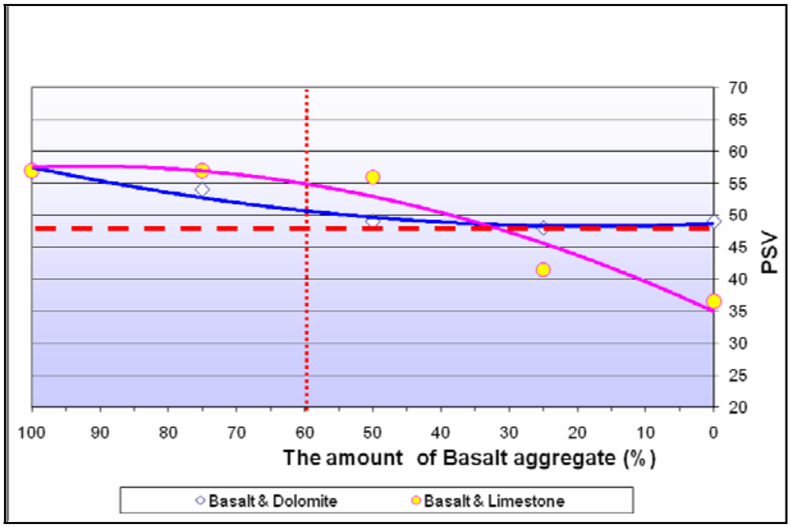


Figure 1: The value of PSV VS the amount of basalts aggregate, feasibility stage

These feasibility tests were repeated later during the preliminary preparation for the construction of the test site in the road. The tests were expanded to include the actual materials and the AC mixtures designated to be used in the test sections. The results of the feasibility test are presented in Figure 2. The results of the preliminary tests were similar to the initial feasibility tests. The specification of the PSV values were achieved at a basalt content of about 50%, and for some compositions- even at lower values – down to about 40%.

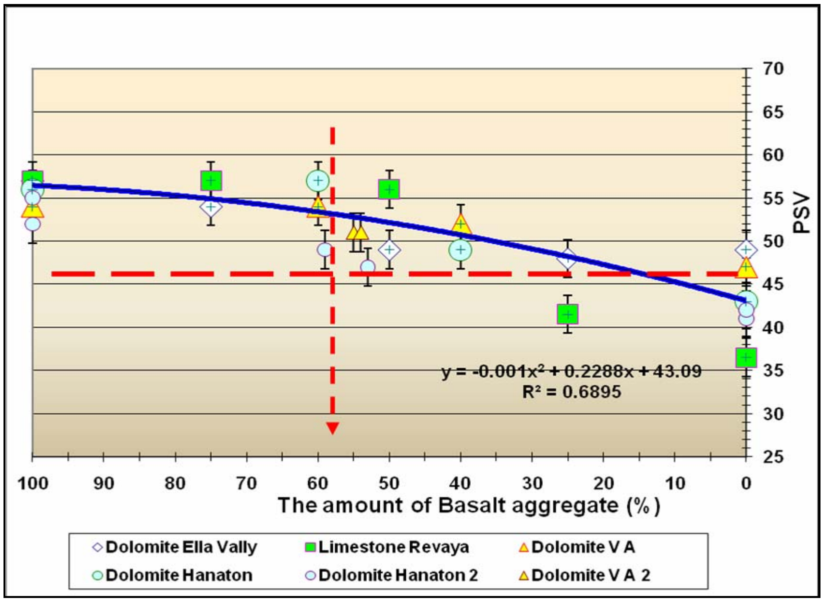


Figure 2: The value of PSV Vs the amount of basalts aggregate, preliminary testing

Table 1: Aggregate characteristics following the preliminary tests

Source of Dolomite aggregate	The abundance of the different Aggregate		Density Kg/m3	Water Absorption %	Los Angeles Abrasion Test		PSV
	Basalt	Dolomite			Method B	Method C	
Shaphir Vadi Arra Quarry	100	0	2781	2.35	14.7	18	54
	40	60	2715	1.93	16.1	18.9	52
	60	40	2737	2.07	15.5	18.6	54
	0	100	2673	1.65	17.1	19.6	47
Henson Hanaton Quarry	100	0	2781	2.35	15.9	19.9	56
	40	60	2721	2.01	15.6	18.8	49
	60	40	2741	2.12	15.4	19.5	57
	0	100	2683	1.78	16.2	19.1	43

The feasibility and the preliminary PSV test were part of the tests program for aggregate which is performed routinely to approve the usage of the aggregate for the AC mix production. The characteristics of the aggregate are described in table 1 above. All the aggregate mixtures that contain Basalt, met all the specifications for aggregate type "A" which complies with the demands for aggregate for wearing course. The samples that contained only dolomite (100%) did not meet the criteria for the PSV.

The conclusions from the feasibility and the preliminary tests are as follows:

- The density of the coarse limestone/dolomite aggregate mixes increases linearly with the addition of basaltic aggregates. The changes in the water absorption values in these samples were small.
- The addition of basaltic aggregates improves the Los Angeles abrasion values even for aggregates that originally do not comply with INRC's specifications requirements of a minimum value for type A aggregate of 25.
- The addition of basaltic aggregates at a weight rate of about 60% basaltic aggregates (or at an industrial / practical ratio of 1:2) ensures, according to laboratory results, that PSV values greater than 48 are obtained.
- The laboratory test results reinforced the project’s premise that it is possible to blend the Israeli basaltic with dolomite/limestone aggregates, to obtain satisfactory results with respect to the resistance of these aggregates mixes to polishing.

Paving of the experimental test site's segments on road 784

Following the successful laboratory tests phase it was decided to construct field test section in order to monitor the production feasibility and the field performance of mixed dolomite/basalt aggregates (referred hereto as "ZEBRA" or "Z-AC" mixtures due to the black basalt and white dolomite mixed appearance). The application of the experimental test site's segments was integrated into the INRC annual overlay project plan in the northern district of Israel. Road 784, in the lower Galilee was assigned for the construction of the test sections. The test section's location is in a hilly road between Kornit junction and Misgav junction, from Km 13.910 to Km 17.515 (see map on Figure 3). The test section is a part of a one-way, two- lane, regional road with an AADT of about 15000 (2008 values) [Ref. 4]. The paving took place during the month of November 2007. A total of 8,870 tonnes of AC mixtures were applied as part of the project, out of which 6,950 tonnes were the experimental Z-AC mixtures.

The main types of AC mixtures used by the INRC are the 19 mm SMA and the 25 mm AC S-Structural (referred to as :"S- Str" in table 2) mixtures (which are based on the US- SHRP "below restricted zone" gradation curve concept). These two types of AC were produced and paved at the test section.

The test section was composed of 8 different coarse aggregate compositions as follows:

- 1 segment (no. 1) - 25 mm AC S-Structural dolomite mix (control segment)
- 1 segment (no. 5) - 25 mm AC S-Structural basalt mix (control segment)
- 2 experimental segments (no.4 and 6) - 25 mm Z-AC S-Structural (two different dolomite sources)
- 1 segment (no.8) - 19 mm SMA- dolomite mix (control segment)
- 1 segment (no.2) - 19 mm SMA- basalt mix (control segment)
- 2 experimental segments (no. 3 and 7) - 19 mm Z-AC SMA- mix   (two different dolomite sources)

All the mixtures were produced in Henson-Hanaton batch plant.

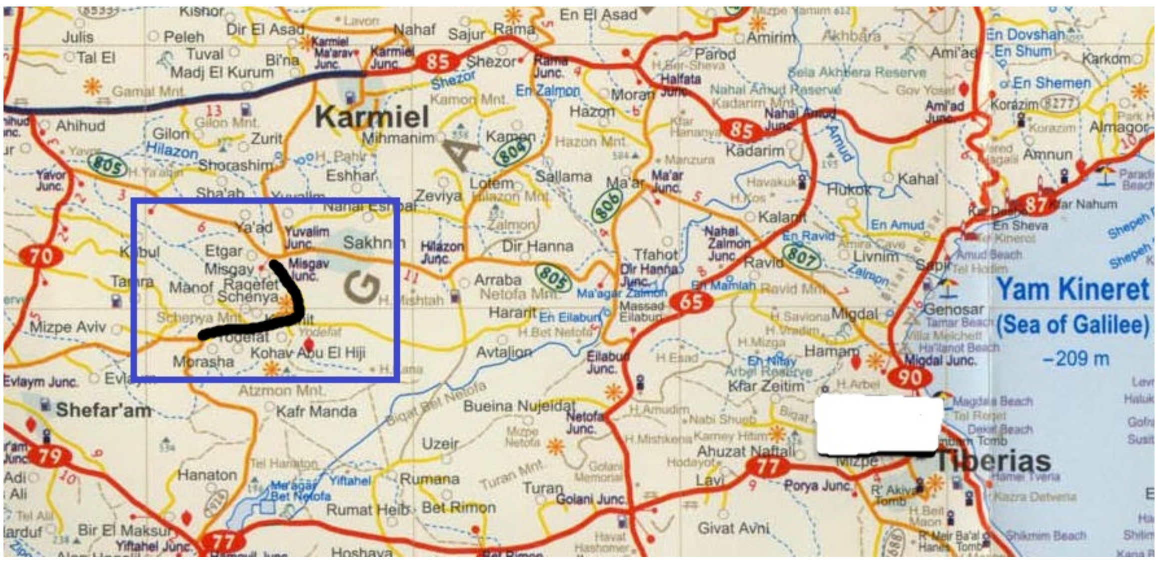


Figure 3: The location of the test sections in the Galilee

Table 2: Approved gradation lines and mixture characteristics - 75 blows Marshall Mix Design

Mixture number	Number of test segment	Mixture type and description	Aggregates and asphalt mix ratio			Gradation line (% passing)									
			Basalt - coarse fraction (%)	Dolomite – coarse fraction	Basalt content in mix (%)	25	19	12.5	9.75	4.76	2	0.84	0.42	0.177	0.074
11	5	S-Str 25 Basalt	**100**	**-**	**65**	100	94	87	68	35	25	14	11	8	6.0
12	4	Z-AC S-Str 25 Henson	**60**	**40**	**41**	100	94	87	68	32	25	14	11	8	6.0
13	2	SMA 19 Basalt	**100**	**-**	**75**	-	100	93	29	25	18	-	-	-	9.0
14	7A ; 7B	Z-AC SMA 19 Henson	**60**	**40**	**45**	-	100	93	29	25	18	-	-	-	9.0
15	6	Z-AC S-Str 25 Shaphir	**60**	**40**	**41**	100	94	87	68	32	25	14	11	8	6.0
16	3	Z-AC SMA 19 Shaphir	**60**	**40**	**45**	-	100	93	29	25	18	-	-	-	9.0
17	8	SMA 19 Dolomite Henson	**-**	**100**	**0**	-	100	93	29	25	18	-	-	-	9.0
18	1	S-Str 25 Dolomite Henson	**-**	**100**	**0**	100	94	87	68	32	25	14	11	8	6.0

Table 2 (cont): Approved gradation lines and mixture characteristics - 75 blows Marshall Mix Design

Mixture number	Number of test segment	Mixture type and description	Aggregates and asphalt mix ratio			Bitumen (%)	F/B ratio	Density (kg/m3)	Stability (newtons)	Retained Strength (%)	Void ratio (%)	V.M.A	Effective density (Kg/m3)
			Basalt aggregate (%)	Dolomite aggregate (%)	Total Basalt content in AC mix (%)								
11	5	S-Str 25 Basalt	**100**	**-**	**65**	4.2	1.43	2430	13344	80	6.0	14.5<	2765
12	4	Z-AC S-Str 25	**60**	**40**	**41**	4.3	1.40	2420	12900	80	6.0	14.5<	2760

		Henson											
13	2	SMA 19 Basalt	**100**	**-**	**75**	5.7	1.58	2390	7117	80	6.4	17<	2800
14	7A ; 7B	Z-AC SMA 19 Henson	**60**	**40**	**45**	5.7	1.58	2380	7117	80	6.5	17<	2795
15	6	Z-AC S-Str 25 Shaphir	**60**	**40**	**41**	4.3	1.40	2405	12010	80	6.0	14.5<	2745
16	3	Z-AC SMA 19 Shaphir	**60**	**40**	**45**	5.7	1.58	2360	7117	80	6.6	17<	2765
17	8	SMA 19 Dolomite Henson	**-**	**100**	**0**	5.7	1.58	2360	6894	80	6.5	17<	2760
18	1	S-Str 25 Dolomite Henson	**-**	**100**	**0**	4.3	1.40	2405	12010	80	6.0	14.5<	2745

The various formulations used in the different test sites are detailed in Table 2 above. The AC mixtures were applied on road segments that were milled before overlaying to a depth of 5 cm. The thickness of the overlayed wearing course was 5 cm.

The major conclusions for the paving phase of the testing segments are specified as follows:

- The experimental Z-AC mixtures were manufactured with no problems, similarly to the "regular/one aggregate type" mixtures. There were no difficulties in assuring that the proper quantities of the different aggregates are assembled in the combined Z-AC mixtures. Figure 4 demonstrates that there is no difficulty in identifying, separating and weighing the different black-basalt and white- dolomite aggregate types after the bitumen extraction from these mixtures. In general all the mixtures that were produced and supplied for the project complied with all the mix-design and specification requirements. Figure 5 presents a view of basalt SMA and Z-AC SMA segments.
- The workability of the experimental Z-AC mixtures was similar to the standard AC mixtures.
- The overall pay adjustment factor rate, for the whole project was very low. This fact attests to the high quality level of the manufacturing and the paving works.

Figure 4: Course aggregate from Z-AC mixtures after bitumen extraction

Figure 5: A view of black basalt SMA and grey Z-AC SMA segments

Periodical monitoring tests

The testing program for monitoring the site included a series of Skid Resistance (SR) measurements using the ROAR system. The ROAR operation procedure was :(1) 86% fixed slip (2) 75 km/h driving speed (3) 0.5 mm film thickness. This procedure of SR testing has been the common practice in Israel since the early 2000's [Ref. 5] both for network surveys and as an acceptance tests for the new surfacing. (The use of the ROAR was stopped in 2010 since the machine went out of service.) Each lane was measured 3 (three) times. Additional in-situ spot testing was conducted using a British Pendulum Tester (ASTM E303) and Texture Depth (TD) tests using Sand Patch (ASTM E965). The Laboratory tests were conducted in March – April 2009. When these measurements took place the test sections have already been under traffic for about 16 months.

During this period additional SR and Mean Profile Texture Depth (MPD) tests were conducted, on the same road for the INRC, as part of the Pavement Management System (PMS) surveys in northern roads. The additional data was collected using the Grip Tester Mark-2 (GT-MK2) system which is equipped also with a laser texture depth measurement system (MPD parameter). The GT-MK2 operation procedure used in Israel is: (1) 75 km/h driving speed (2) 0.5 mm film thickness.

The data from the tests is summarized in Figure 6.

HIGHLIGHTS FROM THE MONITORING TESTING REGARDING THE VARIOUS AC MIXTURES TYPES

General

The results of SR tests clearly indicated the differences in SR and TD values among the various AC mixtures. The SR superiority of the mixtures containing basaltic aggregates over those that contain only dolomite aggregates was significantly clear. This superiority was demonstrated in all the testing systems – the ROAR, the GT-MK2 and the BPN. Since the tests sections included two types of mixtures – with different gradations - SMA and S-Structural, an additional comparison was performed between the performances of these two types of mixtures.

A detailed presentation and analysis of the various tests is detailed below.

Performance of AC "purely" dolomite mixtures

Two AC mixtures were produced purely with dolomite aggregate and serve as control sections. The AC types were S-Structural 25 mm AC mixture (in test segment no. 1) and 19 mm SMA mixture (in test segment no. 8). In order to demonstrate the differences between the various mixtures' performance the SR values scale is divided into three categories in Figures 6 and 7. Referring to Figure 6 the ROAR-SR categories are: (1) satisfactory - below 0.35 which is the minimum acceptance INRC specification requirement for new AC surfacing (2) good- between 0.35-0.45 (3) best- above 0.45. The data clearly indicated that even after a comparatively short service period of 16 months it was possible to identify the inferiority of the dolomite AC mixtures, which are in the "good" category compared to the other AC mixtures that contained any basaltic component which are in the "best" category. This fact was demonstrated in all the various measuring methods that were used. These finding are valid for both, the S-Structural AC mixtures and the SMA mixtures.

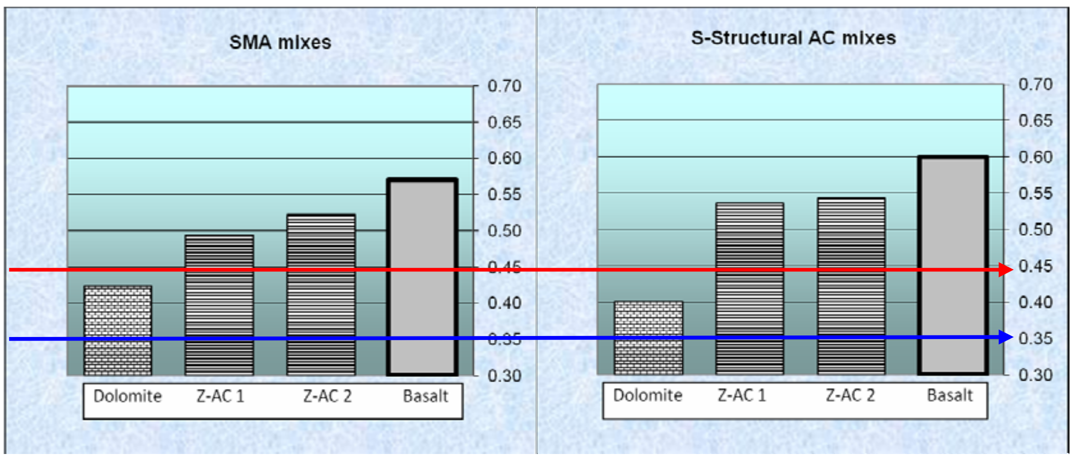
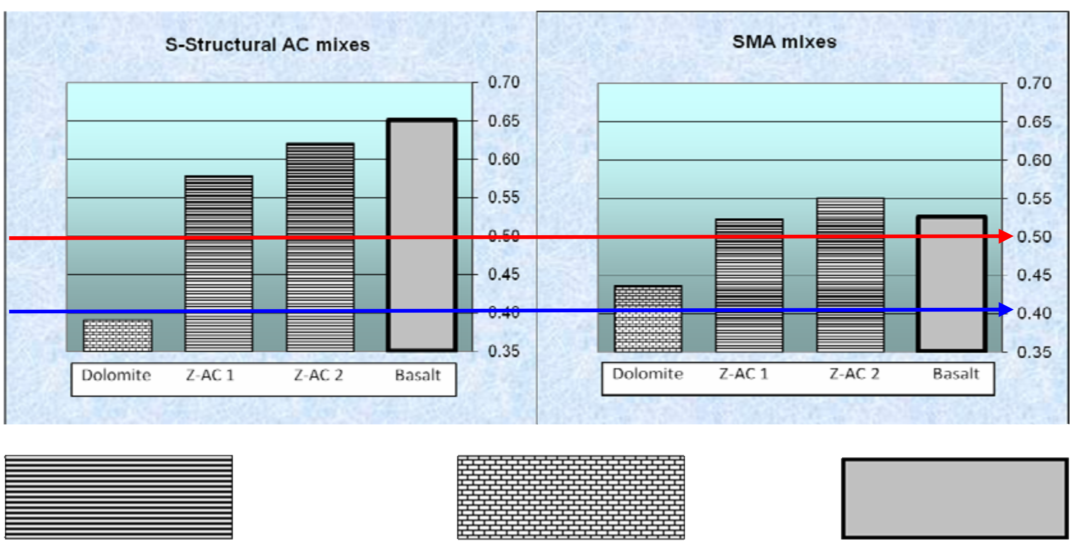


Figure 6: Mu measured by ROAR system



Z-AC mixtures **Dolomite mixtures** **Basalt mixtures**

Figure 7: Mu measured by Grip Tester MK2 system

The SMA mixtures compared to the S- Structural mixtures

Four AC SMA Mixtures were used in five test segments (no. 2, 3, 7a, 7b, 8). All of these SMA mixtures have shown higher TD values than the S mixtures (see Figure 8). This finding is not surprising considering the gap gradation of the SMA compared to S-Structural AC. However, the

SR values of the SMA were in general similar to, and in some cases somewhat lower than those of the S-Structural AC mixtures (see Figure 8). This finding may probably be explained by the higher thickness of the bitumen film on the SMA for which in this short service period was not "eroded" enough to reveal the aggregate surface. Despite the fact that the dolomite SMA mixture texture depth is very close to other SMA mixtures, exhibited SR values that were significantly lower than the Z-AC mixtures, and those of the basaltic AC mixtures. The same phenomenon and conclusion are valid in the case of the S-Structural mixtures.

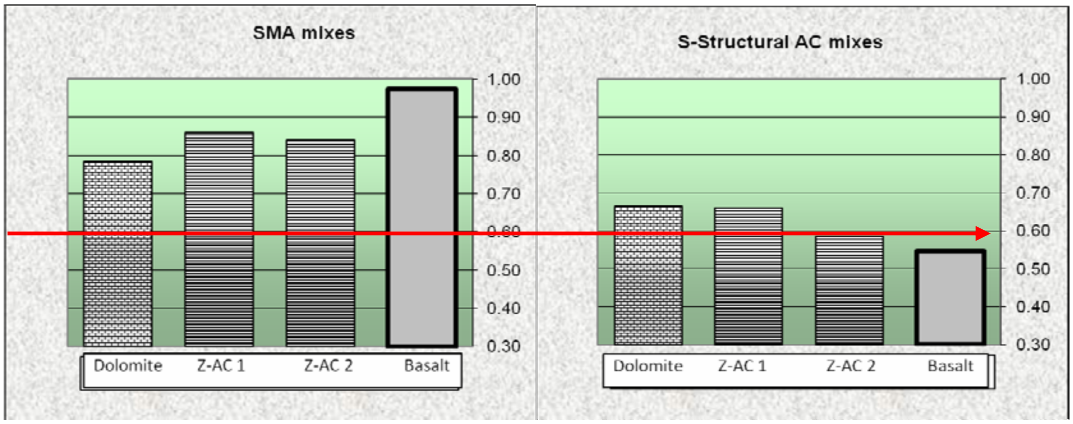
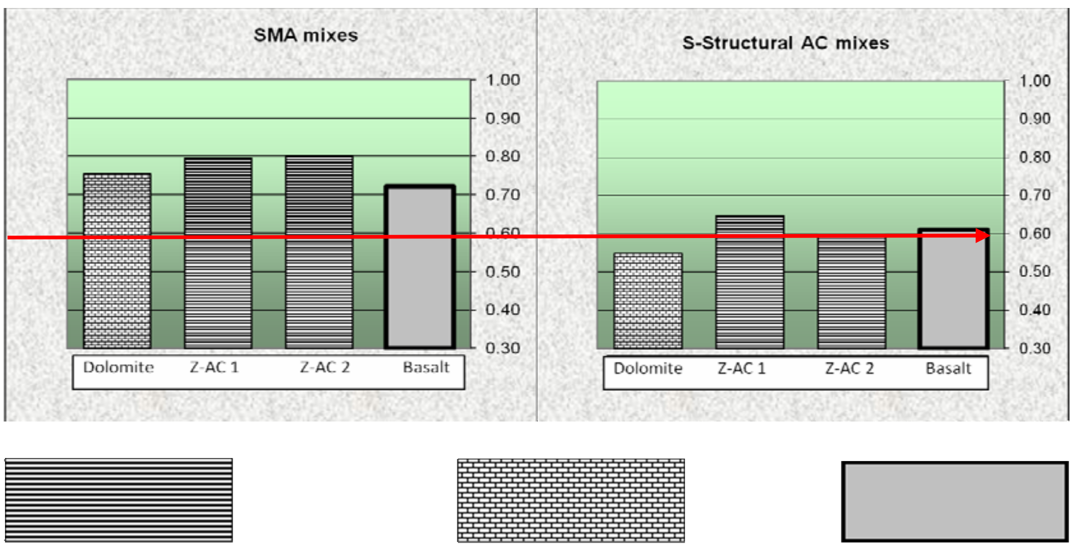


Figure 8: Mean Texture Depth (MTD) using sand patch



Z-AC mixtures **Dolomite mixtures** **Basalt mixtures**

Figure 9: Texture Depth (MPD) using MK2 system

The performance of Z-AC mixtures compared to the other AC mixtures

Four mixtures (in five test segments) are experimental Z-AC mixtures (the amount of basalt is diluted by 40%). The basic evaluation criteria for the Z-AC mixtures, which has been met successfully, is their SR conformance to INRC's specification requirements which is ROAR-SR 0.35. Moreover, as mentioned earlier, these mixtures are all in the "best" SR category and thus, outperform the dolomite mixtures. Furthermore the SR performance of Z-AC mixtures is similar or close to the values of the pure basalt aggregate AC mixtures.

Similar conclusion can also be deduced from measurements obtained from the Griptester MK2 type measurements (see Figure 7).

Expanding the application and continued monitoring of the control segments

Following the April 2009 SR testing additional round of testing has been conducted in March 2010, approximately 28 months after construction. Unfortunately, since the ROAR system went out of service in 2010 the monitoring was continued using the two systems available in Israel: the Dynatest 6875H system (DT) and the Griptester MK2 (GT-MK2) monitoring. For both systems the operation procedure used is: (1) 75 km/h driving speed (2) 0.5 mm film thickness.

Figures 10 & 11 exhibits correlations that were established between the results of the 4/2009 ROAR System and the DT and GT-MK2 3/2010 measurements. The data in the Figures demonstrate that the initial trends detected in the initial monitoring SR tests are still valid generally. However some superiority of the basalt over the Z-AC seems to be developing. At the same time the superiority of the Z-AC over the dolomite is clearly demonstrated.

In addition, some new paving projects using Z mixtures have been constructed in 2010 and are included in the monitoring process.

Updating the INRC specifications and design guidelines

Following the conclusions of this R&D project, the INRC specifications for asphalt paving (Chapter 51.04) and the design guidelines were updated. According to this update, it is allowed to blend basaltic aggregate with dolomite aggregate, if the minimum amount of basalt aggregate in the blend is 40% (by weight) of the total aggregate mix, and 60% (by weight) in the aggregate fraction retained on 4.76 mm (4) sieve.

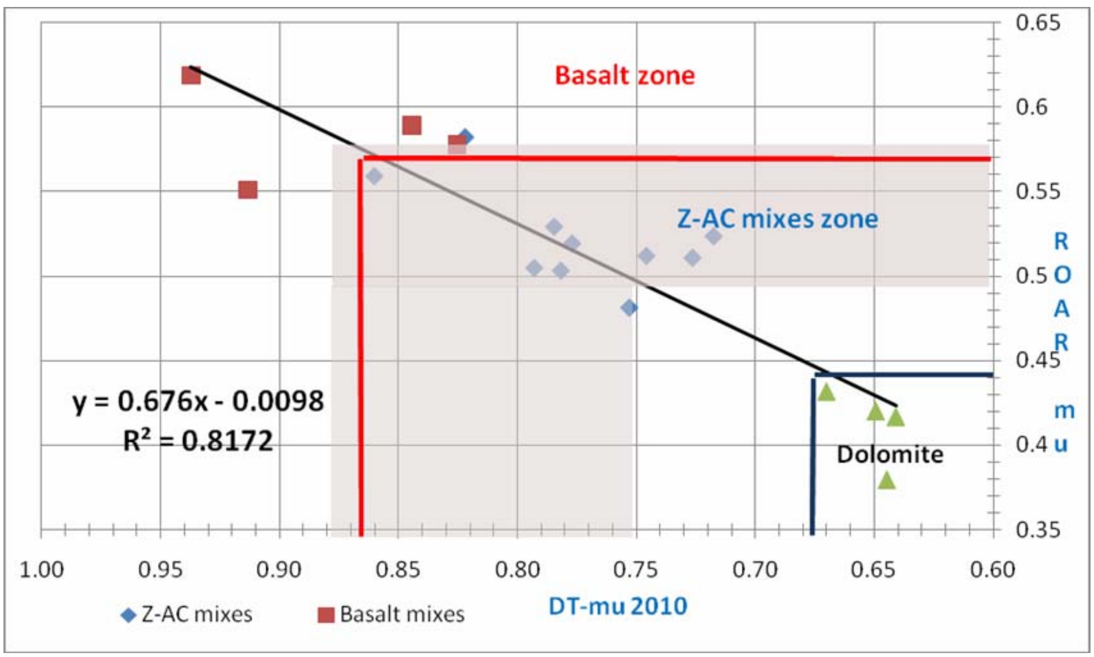


Figure 10: The SR of the various mixtures & the correlation between the ROAR system and the DT system

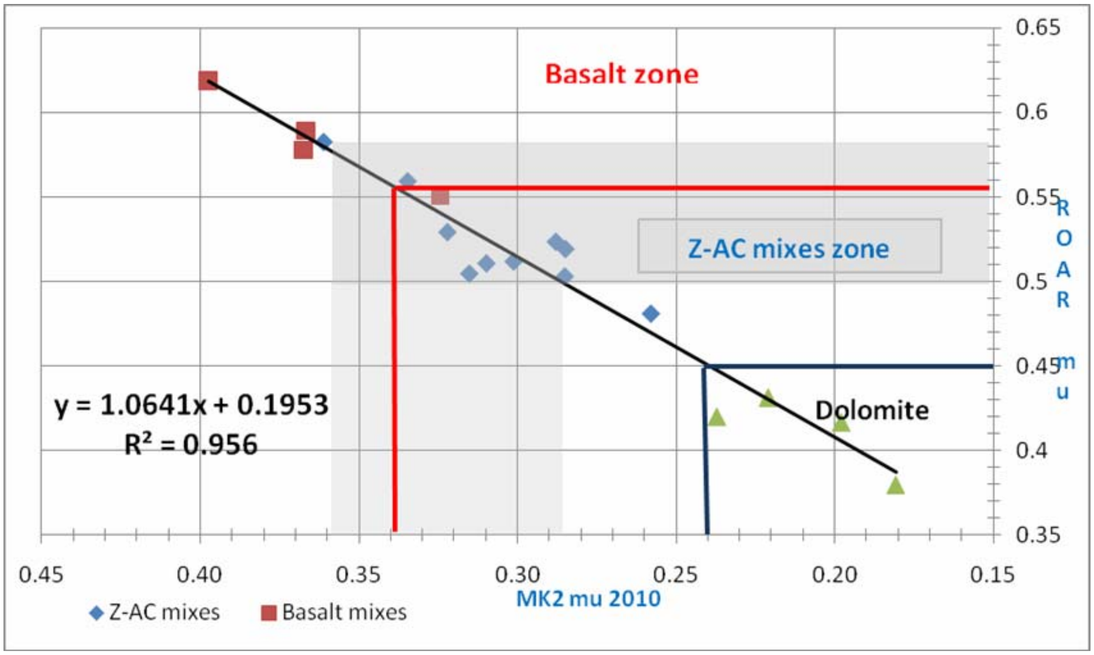


Figure 11: The SR of the various mixtures & the correlation between the ROAR system and the MK2 system

The updated guidelines for the designers states that in roads with a design traffic of an AADT of 5000 to 20,000, or in other roads (with less traffic) that require improvement in the SR , it is required to use Z- AC mixtures. Basalt mixtures are required for roads with AADT of over 20000.

Economic Impact of the research results

In the northern district of the INRC's roads network, about 55% of the total network correspond to the traffic characteristics as cited above in the design guidelines. The amount of basaltic aggregate required to overlay these roads is about 1,100,000 tonnes. Applying Z-AC mixtures, according to the new specification guidelines, may save the usage of about 435,000 tonnes of basaltic aggregate, a very significant amount which corresponds to 55% of the annual demand for basaltic aggregate in Israel.

SUMMARY AND CONCLUSIONS

This paper summarises a research project conducted by the INRC aimed at reducing the amount of basalt aggregate, which is the best in Israel, in terms of polishing resistance, in wearing courses. The premise of the research was that controlled partial replacement of the basalt with the abundant aggregate type in Israel – dolomite, is possible, while still maintaining proper skid resistance (SR) of wearing courses.

The research phases were:

1. Literature survey indicating that controlled blending of high and low PR aggregates is an accepted procedure among road authorities internationally.
2. Extensive laboratory tests of PR (mainly PSV), with varied combinations of Basalt and Dolomite mixtures, establishing the feasibility of reducing the percentage of Basalt in the HMA by 40%.
3. Constructing a four kilometres test section with various HMA mixtures; composed of Basalt, Dolomite and controlled Basalt-Dolomite mixtures (black&white, "ZEBRA" appearance). The "Zebra", Z-AC mixture met the acceptance specification requirements.

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Based on these findings, the Z- AC mixtures were introduced to the INRC's specifications and design guidelines.

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