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Effects of the passage through asphalt mix plants on the quality of aggregate

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ABSTRACT: During the production of asphalt mixes the aggregate constituents pass through the asphalt installation, exposing them to heat and mechanical loading. This can influence the properties of the constituents, and thereby the total asphalt mix. This article discusses the possible influences, focusing on the aggregate. In practice, differences in aggregate properties are far more important concerning the overall quality of the asphalt mix than differences in bitumen properties (Curtis et al. 1993). Therefore, a thorough knowledge and understanding of the properties of the aggregates are vital for a proper functional evaluation of asphalt concrete mixes.

The research involved three different types of asphalt installations: one installation involving a batch mixer with the heating flame in the drying drum directed towards the entrance of the drum, and two drum mixers, one with the heating flame directed towards the entrance and one with the flame towards the exit of the drums. Various aggregates that are presently used in asphalt mixes in The Netherlands have been investigated both before and after passage through drying drums (without the addition of bitumen). The research involved crushing tests and Micro Deval Abrasion tests with an additional sieve analysis of the remains after each test. Furthermore, a petrographic examination of the aggregates has been carried out.

After a discussion of some of the possible effects of heating, drying, and mechanical transport on the aggregates, it will be shown that passage through the installation generally results in a better performance of the aggregates in the tests performed. This is attributed to the fact that loading during passage causes the weakest aggregates to be damaged during their passage. This changes the aggregate strength and the size distribution of the particles during production.

The results of the investigation can be used to determine if a heat resistance standard is necessary and, if so, what such a standard should comprise.

1 INTRODUCTION

The Dutch government wants to promote the application of alternative materials in bituminous mixes. To this end the Road and Hydraulic Engineering Division of the Ministry of Transport and Public Works is involved in the development of so-called functional requirements. These requirements focus on the functionality of the construction rather than the procedures and techniques of constructing. This approach has the advantage that it is easier to apply new or different asphalt mixes. However, it requires a thorough understanding of the relevant material properties, their role in the construction and the extent to which they are influenced by the production processes.

One of the possible relevant material properties is the heat resistance of the aggregate in bituminous mixes. In today's practice only unheated materials are tested. Although practice has shown that in general no problems occur, the application of less conventional aggregate types may prove otherwise.

To gain more insight in the influence of heating on aggregates, the research described in this article was started. It consisted of 1) a review of presently available literature on the subject and 2) a laboratory investigation involving crushing and abrasion tests on different types of aggregates, both before and after passage through industrial drying drums in asphalt installations.

Earlier research has shown that the heating of aggregates may lead to a change of their properties.

These in turn affect the behaviour of the produced asphalt concrete. Curtis et al. (1993), for example, have shown that the properties of the aggregate are the most significant concerning the adhesion between aggregate and bitumen.

The results of the research should indicate if there is a need to give limits and develop test procedures for the heat resistance of road aggregates. To date the research has focused on conventional aggregates. In a follow-up study the previously mentioned alternative materials will be involved.

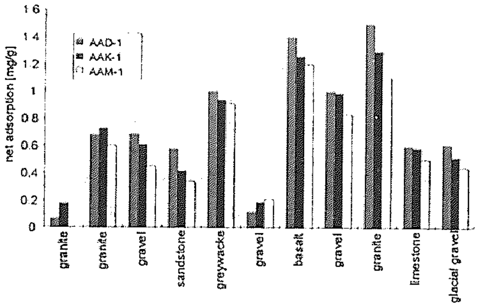


Figure 1 Influence of the type of aggregate and bitumen on the adhesion between aggregate and bitumen. (After Curtis et al. 1993).

2 THE DRYING DRUM

In this paragraph we discuss the basics of the asphalt installations involved in the research focusing on the drying drum. Drying and heating of the aggregate takes place in the drying drum. The drum consists of an inclined hollow cylinder, equipped with internal blades. The rotation speed of the drum lies between 8 and 12 rev/min. A burner is placed at the beginning (concurrent heating) or at the end of the drum (counter current heating). The heat transfer takes place according to a combination of the following mechanisms:

- Radiation from the heat source,
- convection by the hot gasses, and
- conduction from the drum to the aggregate.

If the burner is placed at the end of the drum the aggregate will be exposed to a rising temperature. If the burner is placed at the beginning of the drum, the aggregate is immediately exposed to the highest temperature and subsequently to a decreasing temperature. Together with the mechanical specifications, the configuration of the burner will determine to a large extent the possible influences on the aggregate.

After their passage through the drying drum, the temperature of the aggregate is approximately 170 °C. In case recycled asphalt concrete is used, the additional new aggregate is heated to approximately 275°C. This higher temperature is necessary as the recycled material cannot be heated before mixing (Troost 1995). The exact temperature depends on the type of bitumen that is used (regarding the equiviscosity temperature) and the percentage of recycled material.

2.1 Batch mixer

If a batch mixer is used, the production takes place in a discontinuous process (figure 2). After drying and heating the aggregate is sieved into different fractions. The aggregate fractions and the bitumen are subsequently weighed out and mixed in batches. The batch mixer involved in the research operates according to a counter-current principle, with the burner placed at the end of the drum. In this type of mixer the bitumen is added after the aggregate has gone through the drying drum. The burner is therefore not shielded and thus in direct contact with the aggregate.

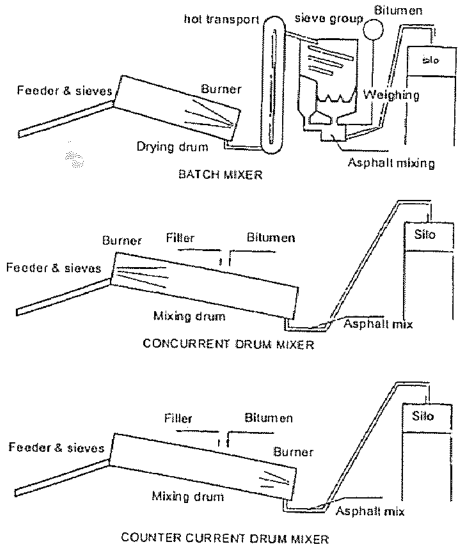


Figure 2 Common types of asphalt installations in The Netherlands.

2.2 Drum mixer

If a drum mixer is used, the production is continuous. Drying, heating and mixing take place within a single drying drum. The correct grading of the aggregate is obtained by means of feeders placed before the drying drum.

Most drum mixers operate according to the concurrent principle, with the burner placed at the beginning of the drum to prevent burning of the bitumen. As an additional measure, the distance between the burner and the location where the bitumen is added is increased by applying a longer drum. A second type of drum, also involved in this research, has the burner placed at the end of the drum. In this type of drum, the burner is shielded to prevent burning of the bitumen.

3 INFLUENCE ON THE AGGREGATE

Due to heating, several processes take place in the aggregate, of which the expansion of the minerals and the evaporation of water are the most important. The water may be present in pores or be adsorbed or structurally bound to the minerals. To what extent these processes will affect the behaviour of the mix depends on the rock properties, the temperature in the drying drum, the capacity of the drum, the rate of the temperature increase and the time the aggregate is exposed to the heat. It should be noted that many aspects of the heat regime in the drum are still relatively unknown. One of the reasons is that drying drums are adapted to the specific needs of the asphalt producer. As a results, even drums of the same type may have different specifications.

3.1 Expansion of minerals

Materials expand upon heating. The amount of expansion and the direction of the expansion depend on the material properties and the temperature. Most rocks, and thus aggregates, are heterogeneous materials, consisting of a variety of minerals that react differently to heating. Also, many minerals do not expand equally in all directions (anisotropy). Furthermore, the expansion is influenced by temperature gradients in the aggregate particles. All these factors lead to the development of internal stresses that can cause cracking and degradation of the aggregate (Szymanski 1989). The highest stresses will develop due to a combination of quick heating, a low heat conductivity, the material heterogeneity and anisotropy and the expansion of water in the aggregate.

3.2 Removal of water

- Evaporation of pore water: Heating and evaporation of water in pores lead to an increase in volume, which results in the development of internal stresses in the aggregate.
- Dehydration: Dehydration is the removal of adsorbed water molecules from the external surfaces (reversible) or from interstices (irreversible). This process is particularly important regarding clay minerals and occurs at temperatures up to about 350°C (Szymanski 1989). The resulting volume changes lead to stresses in the aggregate particle.
- Dehydroxylation: Dehydroxylation is the removal of structurally bound water in the form of (OH) groups. The dehydroxylation temperature depends on the mineral structure. Of greatest importance to clay minerals (350-1000°C) and micas (350-1200°C), it destroys the original mineral structure resulting in volume changes. As a consequence stresses will build up in the aggregate particle (Szymanski 1989).

3.3 Mechanical influence of the drying drum

During the passage through drying drums the aggregate is intensely mixed. As a result the aggregate is subjected to abrasion and impact with as a result the breakdown of weaker particles and the rounding off of edges.

4 PREVIOUS RESEARCH

There have been several attempts to describe the processes that take place in the drying drum and to assess the influence of the drying drum on the aggregate properties in the past. These involved laboratory experiments, full-scale experiments as well as theoretical approaches (a.o. Schlösser 1969, Kohler 1970, Eppensteiner 1974).

The main problem with theoretical approaches is the uncertainty of the conditions inside drying drums and the complexity of the aggregate with regard to its mineralogy and shape. As a result significant simplifications have to be made. This makes the results less reliable (Kohler 1970).

Experiments have shown a large discrepancy between heating in a laboratory and heating in industrial drying drums (e.g., Kohler 1930, Höbeda 1986). The influence of heating depends not so much on the temperature as on the method of

Table 1. Materials used in research with their origin. All materials were sampled before and after the drying drum. MDAV: Micro Deval Abrasion test, DSC: Dutch static crushing test

Code	Description	Asphalt installation type and location	Grading [mm] sampled	MDA	DSC
		concurrent continuous			
GD	River Meuse gravel	Dordrecht	4/32	8/11,2	22,4/32
PD	Porphyry	Dordrecht	2/11,2	8/11,2	8/11,2
MSD	Crushed moraine gravel	Dordrecht	2/16	8/11,2	11,2/16
		countercurrent discontinuous			
PT	Porphyry	Tilburg	8/11,2	8/11,2	8/11,2
NST	Crushed river Meuse gravel	Tilburg	0/22,4	8/11,2	16/22,4
TT	Porphyry (Tilred)	Tilburg	8/11,2	5,6/8	5,6/8
		countercurrent continuous:			
MSB	Crushed moraine gravel	Botlek	8/16	8/11,2	11,2/16

heating, the time of heating and the capacity of the oven/drying drum. Another difference is the degradation that takes place simultaneously with the heating in industrial drying drums.

Although in the laboratory an influence of heating can be established, the generally applied aggregate types are not found to give problems in practice. Aggregate types that deteriorate significantly through heating often have other properties that make them less suitable for application.

5 LABORATORY INVESTIGATION

For the laboratory investigation, samples were taken at different asphalt installations, both before and after drying and heating(table 1). The material, sampled after their passage through the drying drum had been heated to a temperature of 170 °C. The only exception is sample MSB, which had been heated to a temperature of 250°C.

All samples were subjected to the Micro Deval Abrasion test following the French standard NF P 18-572 and the Dutch static crushing test following the RAW standard, test 53.

Micro Deval Abrasion test: 0.5 kg of aggregate particles is placed with 2.5 dm^3 of water and 5 kg of steel balls (diameter 10 mm) in a smooth drum with an internal diameter of diameter of 200 mm. The drum is then rotated for 12000 revolutions within 2 hours, after which the material is washed and dried. The Micro Deval Abrasion value is defined as the weight of the material smaller than 1.6 mm as a mass percentage of the original weight of the specimen. However, we have tested the fraction 8/11 rather than the fraction prescribed in the standard.

Table 2. Summary of test results. <x>: mean of 5 tests, σ: standard deviation. Codes ending with 'K' were sampled before heating(unprocessed), samples ending with 'W' were sampled after heating (processed)

Code	Micro Deval Abrasion test fraction [mm]	<x> (%)	σ (%)	Dutch Static Crushing test fraction [mm]	<x> (%)	σ (%)
GDK	8/11,2	7,66	0,45	22,4/32	46,50	6,73
GDW	8/11,2	7,63	0,51	22,4/32	41,20	4,83
PDK	8/11,2	5,19	0,23	8/11,2	23,70	0,71
PDW	8/11,2	5,11	0,28	8/11,2	22,90	1,16
MSDK	8/11,2	6,54	0,49	11,2/16	33,40	2,11
MSDW	8/11,2	6,31	0,41	11,2/16	32,60	1,44
PTK	8/11,2	5,75	0,31	8/11,2	23,40	0,66
PTW	8/11,2	3,75	0,05	8/11,2	19,80	0,68
NSTK	8/11,2	7,00	0,25	16/22,4	36,80	1,96
NSTW	8/11,2	7,14	0,19	16/22,4	37,00	1,39
TTK	8/11,2	7,89	0,10	5,6/8	28,90	0,72
TTW	8/11,2	6,72	0,31	5,6/8	28,00	0,54
MSBK	8/11,2	6,46	0,21	11,2/16	32,30	1,31
MSBW	8/11,2	6,42	0,34	11,2/16	32,00	1,27

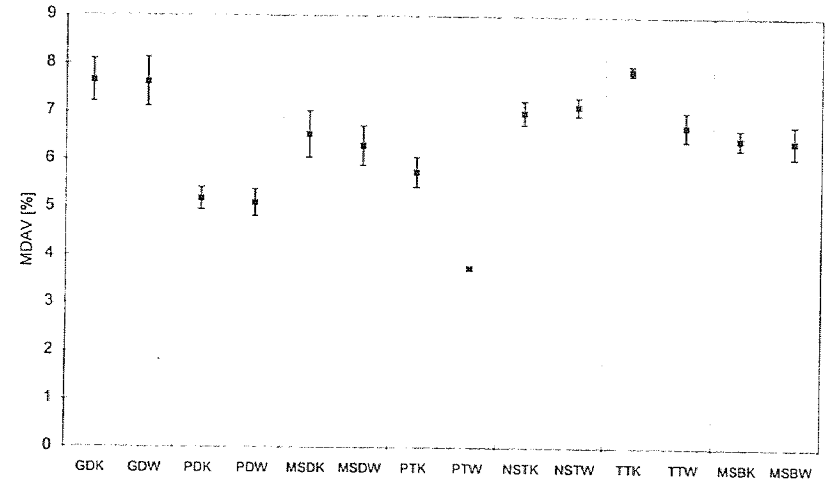


Figure 3 Micro Deval Abrasion Value before and after passage through the drying drum. Mean values with standard deviation as error bars.

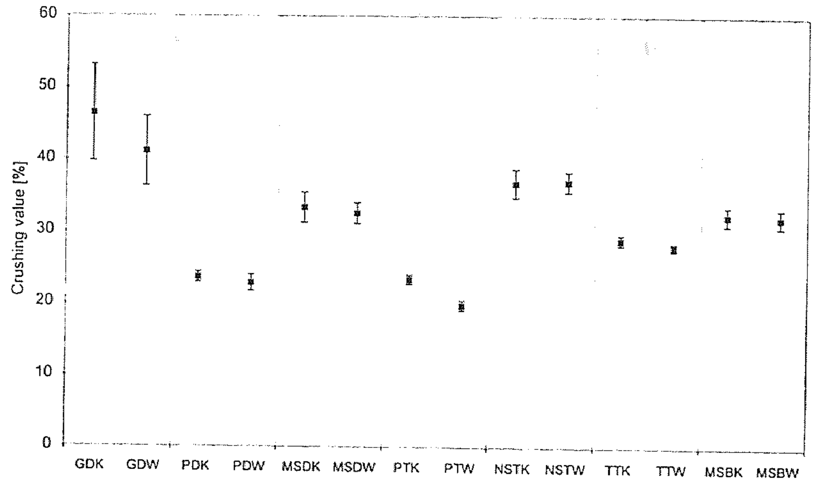


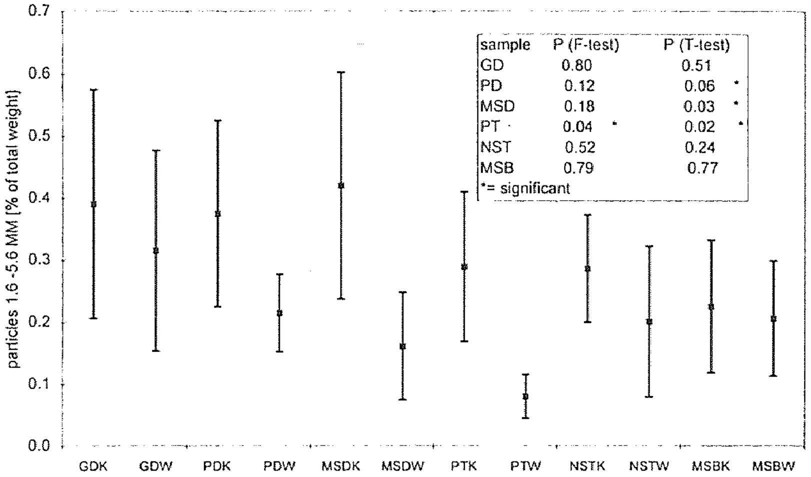
Figure 4 Crushing value before and after passage through the drying drum. Mean values with standard deviation as error bars.

Dutch static crushing test: for this test 0.5 dm^3 of the fraction to be tested is subjected to a load that increases from 0 to 200 kN in 60 seconds, after which the maximum load is maintained during 30 seconds. After testing the material is sieved over a sieve size that is half of the lower fraction limit. The crushing resistance is defined as the amount of material passing the sieve, expressed as a mass percentage of the original weight of the specimen. In this research the largest possible size fraction has been tested (see table 1).

A petrographic examination has been carried out involving a thin section study by transmitted light microscopy as well as surface analysis with stereo binocular microscopy and a scanning electron microprobe (SEM).

6 RESULTS

Table 2 and figures 3 & 4 show the results of the tests. To allow for a statistical analysis 5 specimens of each sample were tested.



sample	P (F-test)	P (T-test)
GD	0.80	0.51
PD	0.12	0.06 *
MSD	0.18	0.03 *
PT ·	0.04 *	0.02 *
NST	0.52	0.24
MSB	0.79	0.77

*= significant

Figure 5 Generated amount of particles between 1.6 and 5.6 mm by Micro Deval Abrasion test.

By comparing the results of the "processed" aggregate (after passage through the drying drum) with the "unprocessed" aggregate, it can be established whether the passage through the drying drum has an influence on the aggregate properties determined. The Student T-test and the Fisher F-test were used to establish whether observed differences were statistically significant or not.

Although all samples show a difference between processed and unprocessed material, these are only significant for sample PT and TT. This is illustrated by figures 3 and 4. The change in the results is related to an improvement of the properties.

After testing, the remains were subjected to a sieve analysis. The reason for this analysis was that a change in properties might have an influence on the strength of the particles. Such a change would show in the grading curve of the material remaining on the sieve used to determine the test result.

As part of the analysis, for the specimens subjected to the Micro Deval Abrasion test the amount of material between 1.6 and 5 mm was determined.

These particles are considered to be formed by fracturing rather than abrasion (considering all samples consist of relatively strong rock). The results are shown in figure 5. The figure shows that the processed aggregate always contains less material within this fraction. This would mean that the aggregate is less liable to fracturing. However, only for samples MSD, PT and PD the changes are significant.

The results of the sieve analysis on crushed material did not show any consequent changes. The main reason for this was that the samples consisted of different fractions.

From the results it can be established that the passage through drying drums does not really influence the abrasion and crushing properties of the aggregate. Although significant for two samples, the changes are so small that they are not of importance from a practical point of view. Furthermore, if a change in the properties takes place this is related to an improvement of the material properties, which agrees with other studies (e.g. Eppensteiner & Krzemien 1974). This can be explained as follows: The passage through the drying drum involves the loading of the particles. Due to this loading the particles are rounded of (abrasion) while protrusions are broken off. Also, the weaker particles will fail during the passage. As a result, after the passage through the drum these weaker particles are absent in the test fraction. At the same time the strength of the aggregate has improved because of rounding off and the removal of protrusions.

It was not possible to detect any difference between the processed and the unprocessed aggregate with the petrographic analysis.

7 CONCLUSIONS AND REMARKS

The results show that in most cases there is no statistically significant influence of the drying drum on the properties of the aggregate as assessed in this study. If an influence is present, it concerns a small improvement of the quality.

It is important to note the boundaries within which this conclusion is valid: The conclusion that the drying and heating does not influence the aggregate properties only relates to its resistance against crushing and abrasion. However, other characteristics, such as adhesion and water adsorption, may be influenced. Also, this research involved high quality materials. Other results may be obtained for alternative materials such as those of marginal quality and aggregates derived from recycled materials. For such aggregate types also the petrography may show a change due to the processing. A difficulty with the petrographic study is that it is performed at room temperature. Cracks that develop at high temperature may close with cooling, leaving no trace of their presence (Hettema 1996).

Previous studies support our results. Eppensteiner & Krzemien (1974), for example, found similar results with regard to the Los Angeles Abrasion Value. Also Höbeda (1986) concludes that in practice little effect is to be expected of the passage through the drying drum.

Presently a follow-up study is considered in which alternative materials will be involved as well as some other characteristics of the aggregate.

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