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Durable and Sustainable Road Constructions for Developing Countries

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Abstract

This paper discusses the possibilities to build durable and sustainable pavement structures in developing countries. Attention will be paid to geometric design aspects which have a significant effect on pavement life. Following this attention will be paid to the importance of controlling wheel loads rather than axle loads. Also the importance of controlling tire pressures is discussed. The paper continues with a discussion on the importance of proper construction. Finally it is shown that re-use of construction demolition waste and hot recycling is very well possible and results in good quality materials which can be used to build durable and sustainable pavement structures.

Keywords: pavement damage; wheel loads; pavement construction; construction and demolition waste; hot recycling of asphalt mixtures.

1. Introduction

When only limited resources are available to build and maintain road networks, then one should use the available resources in the most optimal way. In terms of pavement design and construction this means that pavements should be designed and constructed in such a way that they can sustain large numbers of heavy traffic loads for a long time without showing a significant amount of damage. This does not necessarily imply that one is talking about thick pavement structures. No, it simply means that one has to do things right and one has to anticipate in a proper way on things that cannot be controlled.

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Overloading for example is a serious problem in almost all developing countries. If one wants to prevent development of early and excessive pavement damage, then one has two options. The first option is to enforce axle and wheel load regulations or, if that is not possible for one reason or another, design and construct pavements in such a way that they are able to carry these severe overloadings. This later option however is a costly one while the first option does not necessarily need to cost a lot of money. So why do we not control axle and wheel loads? To a large extent this has to do with the fact that people usually want to exploit whatever that is available to the maximum possible limit without too much concern for the consequences. This later is also true for the environment. We are exploiting Mother Earth to a maximum and we seem not to bother too much about the consequences. We use virgin, "new", materials mostly in an ineffective way and we throw away what we call trash without realizing that this so called "trash" contains very often very valuable materials that can be used again quite easily and quite effectively.

Given the fact that well designed and constructed pavements will limit the need to use scarce resources, and given the fact that taking care of the environment and the necessity to recycle as much as possible so called "waste", this paper therefore discusses how long life pavements can be built using recycled materials. Attention will be paid to geometric design and wheel load issues as well as construction quality. Furthermore attention will be given to recycling of asphalt mixtures and construction and demolition waste. It will be shown that materials with excellent characteristics can be produced using recycled materials.

2. Geometric Design Issues Related to Pavement Life

The geometric design of a pavement can have significant effects on its pavement life. It is a well known fact that the pavement structure at steep gradients and sharp curves suffers from much higher stress condition then the pavement which is laid in a straight section with no longitudinal gradients. Steep gradients and sharp curves result in additional shear stresses which can be the cause of accelerated deterioration especially if the surface layer material is not strong enough or is too aged. Next to that, narrow transverse profiles can also be a reason for rapid deterioration because narrow traffic lanes cause traffic to channel and narrow lanes causing pavement edge loading conditions to occur. Furthermore too narrow lanes have a negative effect on the moisture distribution in an area which is subjected to heavy traffic loads. Both aspects will be discussed in greater detail hereafter.

2.1. Narrow lanes and accelerated damage development

On narrow pavements, the heavy loads come very close to the pavement edge (Figure 1). It has been shown that the tensile strain at the bottom of the asphalt layer of a narrow lane can be a factor 1.05 to 1.2 higher than the tensile strain at the bottom of an asphalt layer of a wide lane because of these edge effects (Molenaar 2007). A 1.05 higher tensile strain means a reduction in pavement life with a factor of about 1.2 while a 1.2 higher strain means a reduction in pavement life of about 2.07! Furthermore too narrow traffic lanes will result in channelling of traffic. If however traffic lanes are wide enough, traffic will show some degree of lateral wander. This lateral wander implies that the maximum tensile strain does not always occur at the same location. Lateral wander is therefore beneficial to pavement life. Depending on the lane width and the stiffness of the pavement, the lateral wander factor which can be taken into account in fatigue analyses can take a value between 1 and 2.5. All in all this means that a pavement with narrow lanes may show a pavement life which can be 5 times shorter than a pavement which is exactly the same but has sufficient wide lanes!

Figure 1. Edge loadings occurring on narrow traffic lanes.

2.2 Narrow lanes are influencing moisture conditions under the pavement

It is a well known fact that moisture has a significant effect on the bearing capacity of the subgrade soil and the unbound subbase and base. The moisture content under the core of the pavement structure is more or less stable, depending on the height of the groundwater level. The moisture content at the edges of the pavement can however be rather variable because of infiltration and evaporation of rain water (see Figure 2). In case of narrow traffic lanes, not only the outer wheels are close to the pavement edge but they are also standing on an area which might have a reduced bearing capacity in the wet season. This situation is further worsened when the side drains are not functioning properly. This again shows that too narrow pavements might deteriorate faster than pavements with sufficient width.

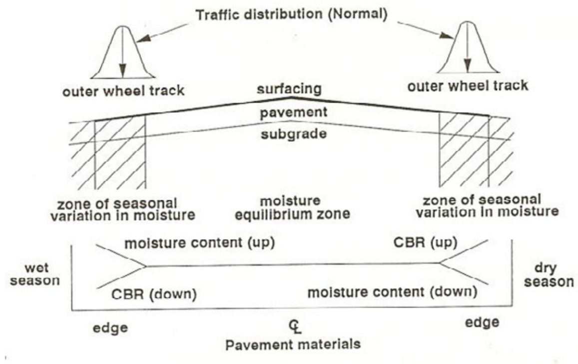


Figure 2. Influence of pavement width on moisture variation in critical areas.

3. Axle and Wheel Loads

Overloading is a serious problem in almost each and every developing country. Two problems however are quite often overlooked which are the very high wheel loads and very high tire pressures that regularly occur. One should realize that an axle load which is within the legal limits still might be very damaging simply because of the fact that the axle load is not equally shared over the wheels of the axle. Some examples of very poor distributions will be discussed hereafter.

Axle load surveys that were performed in a country in West Africa in the early 1990's showed e.g. that especially the axle loads of timber trucks were very unequal divided over the wheels on either side of the axle (Kumapley and Molenaar 1996). A 124 kN axle load e.g. was carried for 32.5% by the dual wheel bogie at the left side of the axle and for 67.5% by the dual wheel bogie on the right hand side. The load on the right hand side dual wheel bogie was carried for 95% by the inner wheel and for 5% by the outer wheel. This was caused by the fact that a tire with a smaller diameter was placed on the outer wheel. All in all this meant that a wheel load of 80 kN occurred!

Given the fact that the legal axle load limit was 100 kN (so 25 kN per wheel assuming a dual wheel on either side of the axle), this 80 kN wheel load was producing approximately 105 times more damage than one would expect! Based on the axle loads however one would expect only 2.4 times more damage due to the 124 kN axle compared to the legal limit axle load of 100 kN. From this simple example it is clear that only axle load enforcement is not enough. Control on wheel loads and equal sharing of the axle load is of equal importance!

Another important issue is the tire pressure. The contact pressure underneath a tire is related to the tire pressure and therefore tire pressures should be limited to reasonable levels. The same study in West Africa revealed that the average pressure in the tires of the wheels of the towed axles was approximately 850 kPa while the highest measured value was 980 kPa (Kumapley and Molenaar 1996). The standard deviation was approximately 52 kPa. Pressures measured in the tires of the wheels of the drive axle however showed an average value of approximately 780 kPa while the maximum values measured amounted 1015 kPa!

It will be no surprise that the combination of high wheel loads and high contact pressures is devastating for the surface layer as well as for the pavement structure as a whole.

Although it will not be discussed in this paper, it can also easily be shown that trucks with poorly maintained spring-suspension systems are heavily contributing to pavement damage.

From a pavement management point of view it is therefore clear that one should pay a lot of attention to the condition of the truck fleet and the overloading conditions. A lot of public money and resources can be saved if the truck fleet is well inspected and axle as well as wheel load regulations are enforced.

4. Influence of Construction Quality on Pavement Life

Durable pavements can only be built if the construction quality is up to standard. Skilled and well trained personnel are absolutely needed to “get the job well done”. Of course proper functioning equipment is a prerequisite. Figure 3 gives an example of the temperature variation that occurred during the production of an asphalt mixture.

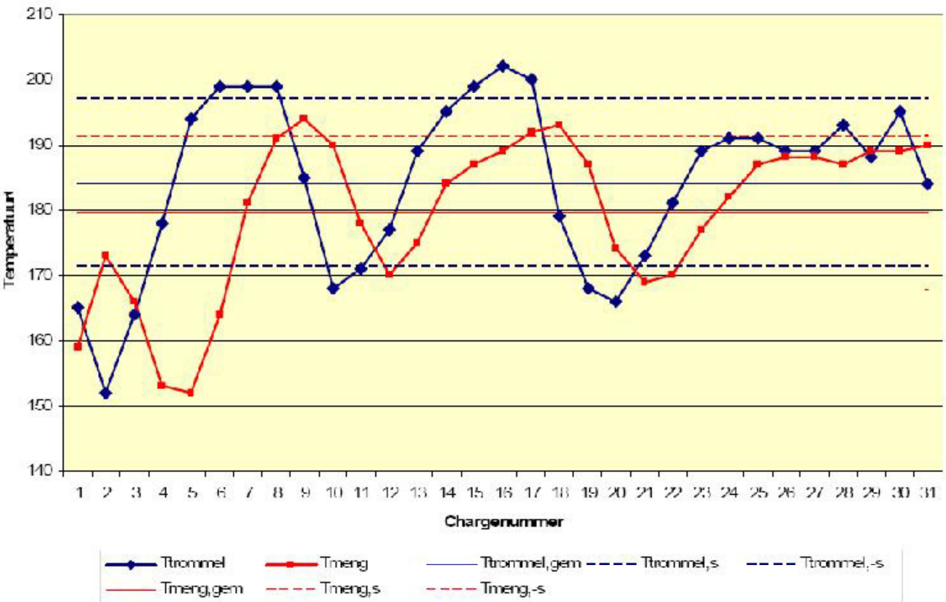


Figure 3. Variation of the temperature in the drying drum (blue line) and mixing unit (red line).

Figure 4 shows the variation in compaction effort that was observed on a regular paving project in the Netherlands.

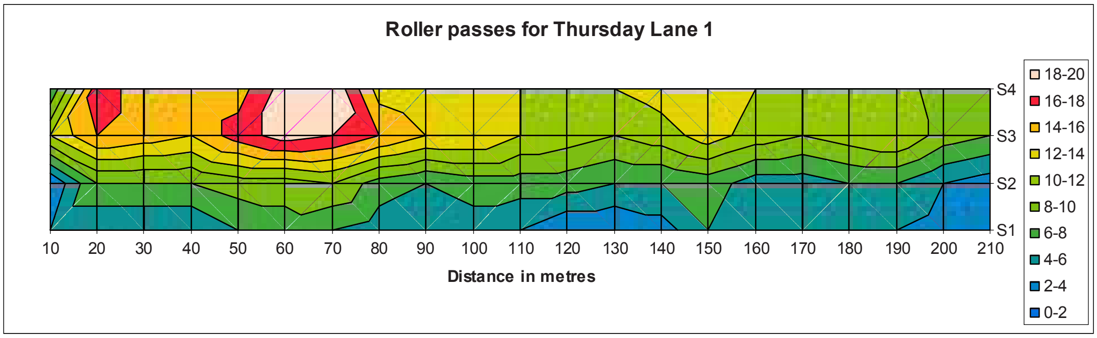


Figure 4. Variation in compaction effort.

From figures 3 and 4 it is quite obvious that significant variations in pavement quality will occur because of variations in mixing temperature and variations in compaction effort. Many more sources of variation can be pointed at. Other examples are segregation of the mixture, temperature segregation, cooling down of the mixture during transportation, excessive moisture in the aggregate storage bins when these are not covered by a shed etc etc. It is clear that one needs not to be a rocket scientist to solve these particular sources of variation. It only asks for good workmanship and the willingness to solve these problems in order to arrive to better performing pavement structures.

5. Recycling

Especially in densely populated areas, recycling of so called waste is a must. Through recycling use of scarce virgin materials is overcome, huge transportation costs related to transportation of virgin materials are overcome, sanitary and environmental problems are overcome etc.

Furthermore valuable space which is used for dumping waste can be used for much more useful purposes in case the waste is being recycled.

Vast experience with recycling in Western Europe in general and especially in the Netherlands in particular has shown that recycling and re-use does not happen by itself. In order to successfully introduce recycling, the government should take a very active position and it should show a great willingness to co-operate with industry. In the Netherlands, the government has been extremely active in developing and enforcing environmental and recycling related policies. One of the regulations was e.g. making dumping of old asphalt and construction and demolition waste very expensive. Next to that the government was very supportive in stimulating research into e.g. the mechanical characteristics of recycled materials and in stimulating industry to develop and purchase necessary equipment etc. Since the early 1990's recycled asphalt mixtures as well as recycled construction and demolition waste are treated like virgin materials in the standards and specifications.

In this section, 2 important recycling issues will be discussed. The first one is the recycling of construction and demolition waste while the second one is the hot recycling of asphalt mixtures.

5.1. Recycling construction and demolition waste

In the Netherlands approximately 1 million tonnes of construction and demolition waste (CDW) is produced per inhabitant per year. In China this number is approximately 0.2 million tonnes per inhabitant. In the Netherlands approximately 95% of the CDW is re-used as base or subbase course in roads. In order to be able to do so, selective demolition is needed. Buildings are first of all stripped from all wood, gypsum plates, asbestos plates etc. In this way, a rather "clean" building is obtained which can easily be broken down. The large blocks are then taken to a crusher to get the desired gradations. During the crushing process electro-magnets are used to take out all metals and metallic parts. Figure 5 is giving an impression of the crushing process.

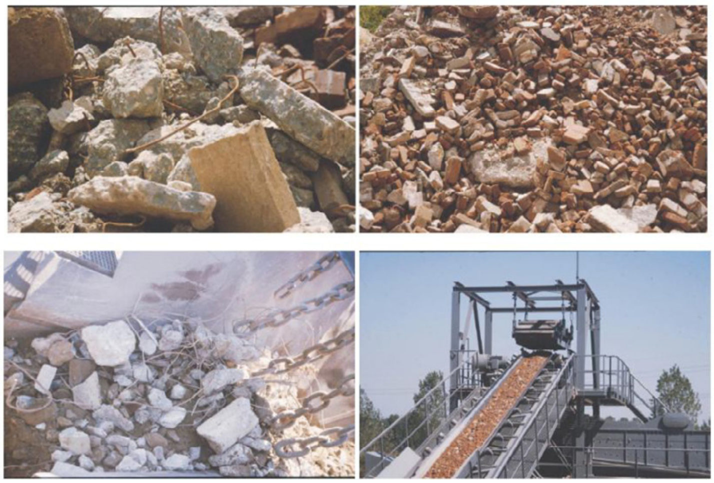


Figure 5. NW: concrete waste; NE: masonry waste; SW: crushing process SE: crushed material and removal of metal parts

5.2. Mechanical characteristics of mixtures of crushed concrete and crushed masonry

Extensive research on the mechanical characteristics of mixed granulates has been done by van Niekerk and some of his results will be shown here-after (van Niekerk 2002).

Figure 6 shows the different gradations that were used in the research program. The codes of the different gradation curves are also used in other figures.

Figure 7 shows the results of monotonic triaxial tests to failure. These tests were performed on large samples having a diameter of 300 mm and a height of 600 mm. Confinement was realized by partial vacuum which implied that the moisture content could not be varied.

Figure 7 clearly shows that the cohesion c of the materials increases with increasing amount of fines (UL gradation has more fines than the LL gradation; see also Figure 6). Furthermore the figure indicates the large influence of the degree of compaction on the cohesion. As expected the angle of internal friction is hardly influenced by compaction.

Figure 8 shows the dependency of the resilient modulus on the bulk stress as well as the influence of the degree of compaction. Again one will notice the significant influence of compaction on the performance of these materials.

The indicator "J" in Figure 8 means that crushing was done by means of a Jaw crusher. In the research different crushers were used in order to determine whether the type of crusher had an influence on the mechanical characteristics. This influence was only marginal and can be neglected.

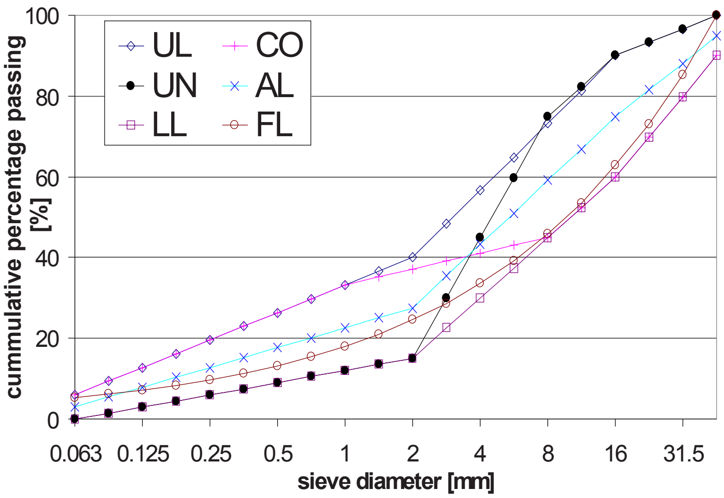


Figure 6. Gradations as used in the research program on mixed granulates

Finally figure 9 shows results from repeated load triaxial testing which were all performed at a confining pressure level of 12 kPa (this value is representative for the horizontal compressive stress that occurs in granular base courses of pavements as built in the Netherlands). The vertical axis gives the ratio of applied vertical stress to the vertical stress at failure at the same confinement level. As one will observe, a stress ratio of about 0.3 – 0.35 is allowed if one wants to limit the permanent deformation to 1% after 10^6 load repetitions. This level of deformation would be allowable in a perpetual pavement since it would mean 3 mm of permanent deformation after 10^6 load repetitions in a 300 mm thick base course.

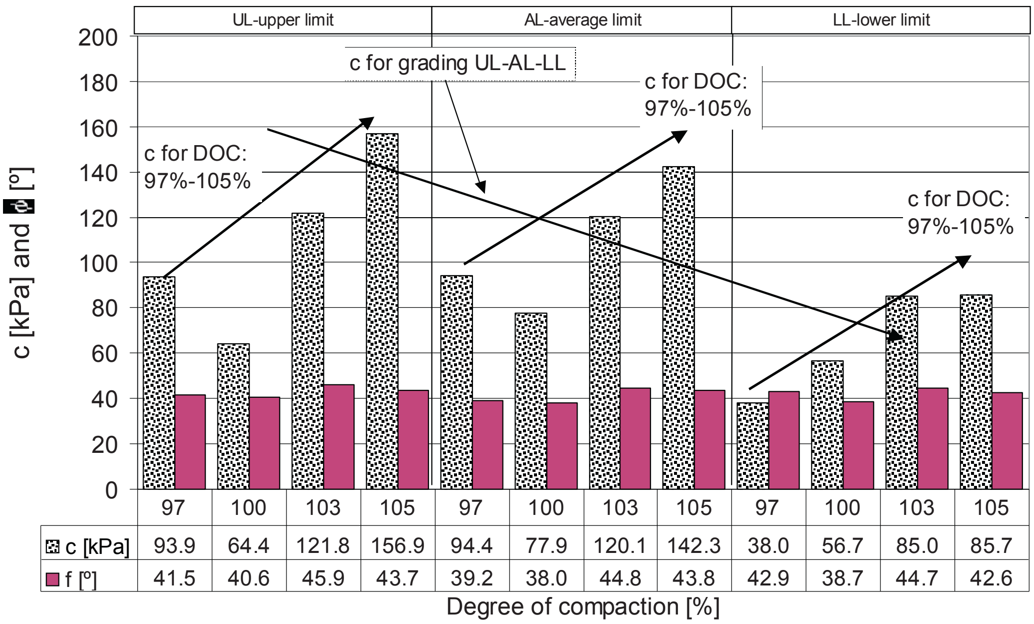


Figure 7. Results of monotonic triaxial tests to failure

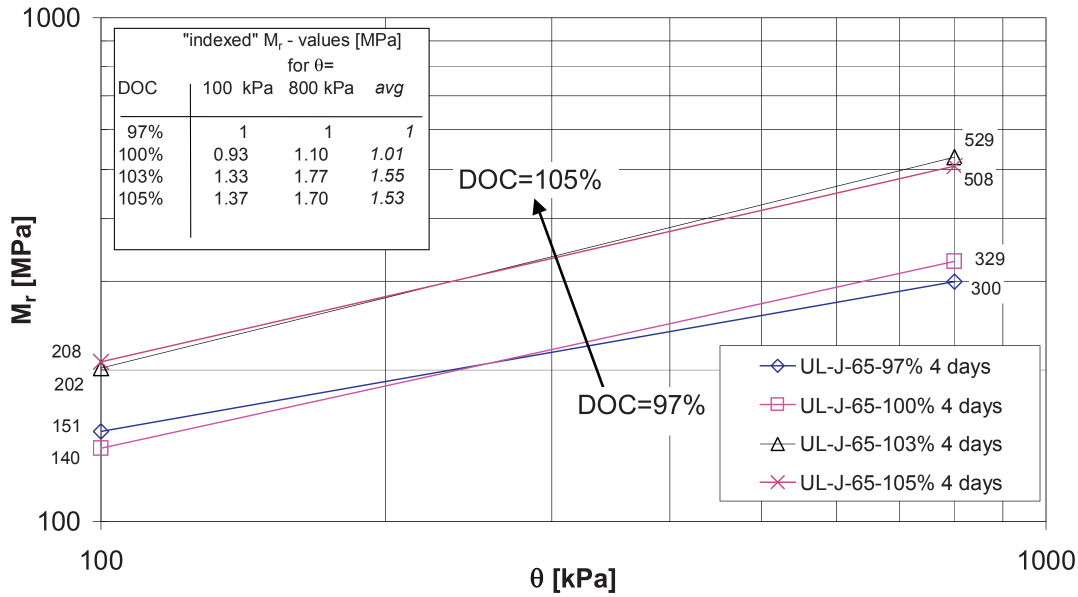
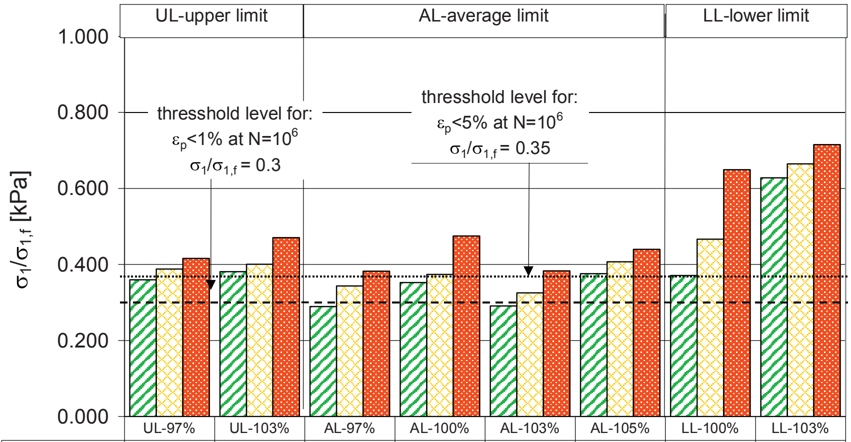


Figure 8. Results of resilient modulus testing

Research has shown that the resilient characteristics of mixtures of crushed masonry and crushed concrete are as good as those of high quality crushed stone (Araya 2011). However it has also been shown that the σ_1 / σ_{1f} ratios that can be allowed on good quality, well compacted crushed stone are in the order of 0.5. This indicates that the resistance to permanent deformation of high quality crushed stone is somewhat better than that of well compacted mixtures of crushed concrete and crushed masonry. This in turn indicates that mixtures with recycled CDW can be very well used in subbase layers where the stress levels are relatively low. One should be a bit cautious when using them as base course in flexible pavements with a thin wearing course.



	UL-97%	UL-103%	AL-97%	AL-100%	AL-103%	AL-105%	LL-100%	LL-103%
1%-N=1000000	0.360	0.381	0.289	0.352	0.291	0.376	0.371	0.628
5%-N=1000000	0.388	0.401	0.343	0.374	0.325	0.407	0.467	0.665
10%-N=50000	0.416	0.471	0.382	0.475	0.383	0.440	0.649	0.715

Degree of compaction [%] and grading (UL-AL-LL)

Figure 9. Resistance to permanent deformation of mixtures of crushed concrete and crushed masonry.

5.3. Hot recycling of asphalt mixtures

Recycling of reclaimed asphalt (RA) in hot mix asphalt is a well know technology for many years. In the Netherlands approxi-mately 0.2 ton RA is produced per year per inhabitant. In the Netherlands 80% of the RA is re-used in hot mix asphalt. A maximum of 50% RA is allowed in the bituminous base, binder and dense asphalt concrete wearing courses. No RA is allowed in SMA while 20% of RA is allowed in porous asphalt concrete.

The most common way to produce recycled asphalt mixtures is to preheat the RA in a parallel drum to a temperature of about 130 ^{0}C. The virgin aggregates have to be heated to temperatures well above 200 ^{0}C to arrive to a mix temperature of about 170 ^{0}C. It is obvious that the temperature to which the virgin aggregates have to be heated is dependent on the amount of RA added to the mixture. The penetration grade of the bitumen to be added is determined by means of the log(pen) rule which is:

$$a * \log(pen1) + b * \log(pen2) = (a+b) * \log(penmix)$$

where: a = volume percentage of binder coming from the RA

b = volume percentage of new binder

pen1 = penetration of the binder coming from the RA

pen2 = penetration of the new binder to be added

Because maintenance of the existing road network is becoming a much more important issue in the Netherlands than the buil-ding of new roads, there is a tendency to increase the amount of RA in asphalt mixtures. It has been shown by Rasenberg contractors that mixtures made with 100% RA can be made provided that the RA binder is rejuvenated with a special vegetable oil. Furthermore it has been shown that fractionizing the crushed RA and storing it in different bins is important to keep a good control over the quality of the recycled mixture. Figure 10 shows how the various RA fractions are stored separately at Rasenberg contractors.

Figure 10. Storing RA aggregates in different fractions.

Table 1. Binder content related to RA aggregate size.

Fraction size [mm]	0 - 2	2 - 5	5 - 8	8 - 11	11 - 16	16 - 22
Mass percentage of total aggregate fraction	22	21	15	18	16	8
Percentage of binder in that fraction	33	25	11	13	13	5

The importance of fractionizing is shown in Table 1 which indicates that the fine fractions of the RA are carrying most of the RA binder. The fractions smaller than 5 mm amount 43% by mass of the total aggregate fraction but they carry 58% by mass of the total amount of RA binder.

5.4. Mechanical characteristics of hot recycled asphalt mixtures

Table 2 shows some mechanical characteristics as determined for several recycled mixtures made with different amounts of RA. The table also shows the mechanical characteristics of recycled mixtures which also include shredded bituminous roofing material. The table clearly shows that recycled mixtures containing a high amount of RA and shredded bituminous roofing material can be made which comply with the specifications according to the European norms. This in turn implies that good quality roads can be built using asphalt mixtures having high RA contents.

Table 2. Some mechanical properties of hot recycled asphalt mixtures.

	E^* max [MPa] At 20 ^{0}C and 8 Hz	$\varepsilon_{fatigue}$ at N = 10^6 at 20 ^{o}C and 30 Hz [µm/m]
Base course mixture requirements EN	**11000 - 14000**	**80 - 100**
Mixture with 100% RAP + resin	**15647**	**101**
Mixture with 70% RAP + resin + roofing	**10219**	**139**
Mixture with 45% RAP + resin + roofing	**10164**	**139**

6. Conclusions

Several aspects have been discussed in this paper. First of all it has been shown that a proper geometric design can result in significant longer pavement lives. Especially the pavement width is a factor to consider. Furthermore it has been shown that excessive wheel loads should be overcome. Measuring axle loads only is not enough. Time and money spent on vehicle controls should really incorporate control of wheel loads and tire pressures. It also has been shown that proper control during pavement construction could overcome building in weak spots during construction. Proper equipment as well as well trained and dedicated personnel are key factors in achieving this. Finally it has been shown that re-use of construction and demolition waste as well as hot recycling of asphalt mixtures is an excellent way to reduce the need to use virgin materials and is an excellent way to re-use so called construction waste. All the aspects discussed do not require large investments or fancy equipment. Therefore it is believed that durable and sustainable pavement structures can also be very well built in developing countries. It is however important that the government develops active policies to promote and stimulate recycling of building materials.

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