Reuse of construction and demolition waste in the Netherlands for road constructions

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1. Introduction

In the Netherlands, the use of secondary raw materials is strongly promoted by the authorities and by industry. This is for the most part a direct result of the rising costs of waste disposal and the limitations on the extraction of primary raw materials from Dutch soil. The demand for raw materials for construction purpose in the Netherlands is estimated at 150 Mtons/year, the amount of construction and demolition waste (CDW) is estimated at 15 Mtons/year (Figure 1).

More than 90% of secondary raw materials are currently used in road construction. Use in concrete is only marginal because of higher costs compared to primary raw materials. Exceptions are blast furnace slag used for blast furnace cement (a more than 50% share in the Dutch market) and E-fly ash. The application of crushed concrete mixed with masonry for the manufacture of sandlimes tone bricks, and aerated concrete is being investigated but seems problematic because current specifications concerning strength, colour, and leaching can not always be met.

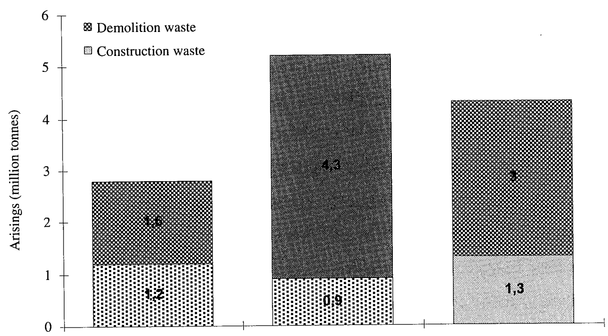

Figure 1. Demolition and construction waste arising in building industry sectors (excluding pre-crusher fines).

Landfilling these wastes would result in a loss of raw materials, undesirable pollutant emissions, energy loss and space use. The waste volume has to be reduced and the released materials have to

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be reused wherever possible to minimise their undesirable environmental impacts.
The national government has laid down its objectives for prevention and reuse in the 'Implementation Plan for Construction and Demolition Wastes'. One of the objectives of this plan is to minimize landfill or incineration of CDW. In this context, reuse includes product reuse, material reuse or the beneficial application of wastes, such as the use of secondary aggregate in road construction or incineration with energy recovery. The latter two types of reuse concern processed CDW. In view of the objective of fully closing the construction industry materials cycle and preventing dispersion of contamination the use of unprocessed CDW is not considered as reuse.
The term 'life cycle management' used in this study refers to reusing materials for their original application. Figure 2 illustrates the trends in reuse and landfill/incineration percentages envisaged in the Implementation Plan.

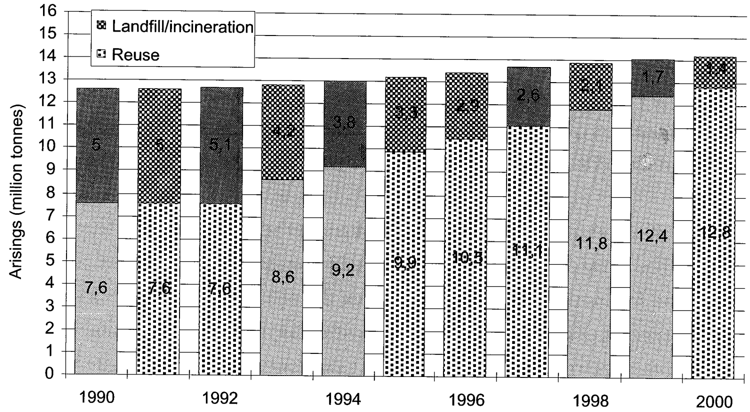

Figure 2. Construction and demolition wastes Programme objectives, excluding pre-crusher fines.

In view of the objective of closing the construction industry materials cycle to the greatest extent, closing the materials cycle would be preferred over the beneficial application of wastes. Materials should be used as construction materials as often as possible. As the potential product reuse percentage will be limited for the foreseeable future due to the construction methods used in the past and at present, closing the raw materials cycles will have to be based on returning the arising materials to their production processes. Over 90% of CDW production consist of hard stony materials such as masonry (clay brick) and concrete; a minor part consists of natural stone. The remaining CDW includes wood, metals, packaging waste and plastics (see figure 3).

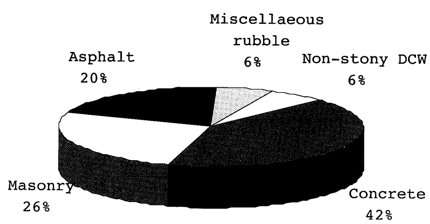

Figure 3. Composition of CDW in 1994 (% v/v)

At present most of the hard CDW's processed and then used as aggregate in civil engineering applications and road construction. The volume that this sector can accept may be limited and furthermore CDW quantities and qualities will change in the future. Given the change in the use of construction materials compared with past practice, demolition of younger buildings is likely to produce more concrete, and the proportion of sand-lime bricks (calcium silicate bricks), plaster and aerated concrete in the waste will increase.

2. Use of construction and demolition waste aggregates in road construction

In the Netherlands, 85% of construction and demolition waste is processed and made suitable for use in road construction or in concrete. Asphalt, too, is largely recycled. Table 1 shows the most important applications.

Table 1. Area of use of recycled aggregates

Type of recycled aggregates [1] Use	RCA	RA	RMA	RHMA	RSA	RCS	AG	BAG
Road construction Sub-base	+	+	+	+	-	-	-	-
Stabilised layer	-	-	-	-	-	-	+	+
Sand for embankment and filling	-	-	-	-	-	+	-	-
Sand for subgrade	-	-	-	-	-	+	-	-
Aggregate								
• Lean concrete	+	+	+	-	+	+	-	-
• Asphalt-bound aggregate (containing tar)	-	-	-	-	-	+	+	-
• Asphalt mixtures	-	-	-	-	-	-	+	-
Concrete construction Aggregate in concrete	+	+	+	-	+	+	-	-

[1]
RCA = recycled concrete aggregate
RA = recycled mixed aggregate
RMA = recycled masonry aggregate
RHMA = recycled hydraulic mixed aggregate
RSA = recycled sand aggregate
RCS = recycled crushed sand
AG = asphalt aggregate containing tar
BAG = asphalt-bound aggregate containing tar

Technical requirements for road construction

A stone sub-base is used to improve the load-bearing capacity and must be well compacted and moisture and frost action resistant. Crushed concrete (and other) rubble is fully accepted as a high-grade stone sub-base material. This is partly because of thorough research and experience gained through a growing number of projects. It is recommended not to mix crushed rubble with other primary or secondary raw materials. Both from the engineering and the environmental point of view, this frequently impairs the crushed rubble; negative associations can occur rapidly through blending with the usually low-grade products. Furthermore experience with these mixtures is lacking in contrast to crushed rubble; the materials have been examined less closely and clear guidelines are lacking. Incidental fantasy mixtures therefore have to be avoided. Any use could, in the longer term, endanger the use of alternative materials. Tables 2-4 summarise the most important Dutch specifications for crushed rubble.

Table 2. Summary of composition requirements

	Main component	side component
Recycled concrete aggregate	min. 80% crushed concrete with dry destiny > 2100 kg/m^3	max. 10% different stone and max. 5% asphalt
Recycled masonry aggregate	min. 85% crushed stone with dry destiny > 16000 kg/m^3	max. 15% different stone and max. 10% asphalt
Recycled mixed aggregate	min. 50% crushed concrete with dry destiny > 2100 kg/m^3 and max. 50% crushed stone with dry destiny > 1600 kg/m^3	max. 10% different stone and max. 5% asphalt

The technical qualities of recycled concrete aggregates are quite similar to those of recycled mixed aggregates. Technical requirements for the use of stone mixture as a sub-base in road construction and as an embankment and a filler have been recorded in the so-called Standard RAW (Rationalisation and Automation in Road Construction) Road Specifications.

Table 3. Requirements for sub-base according to the Standard Road Specifications (RAW) 1995

Requirements for sub-base
- in foreign components - crushing factor exceeding 0.65 - grading within limits, sieve size between C45 and C20 (mm) - max. 10% (m/m) round and unbroken pieces of sieve C4

Table 4. Requirements for filling embankment materials according to Standard Road Specifications (RAW) 1995

Requirement for filling and embankment materials
• the materials has to be of mineral origin; • the material has to be inert, i.e. not dissolve in water; • the material may contain a portion of fine parts < 63 µm of 50% (m/m), in practice, however, therequirement of sand for a sand bed is used (max. 15% (m/m) < 63 µm; • the material may not contain more than 3% (m/m) of organic material; for use as embankment material the materials has to be crushed to max. 45 mm; the resulting product has to be graded evenly for compacting purposes; with a view to stability an compactability, it seems advisable for the time being to use the grading of stone sub-base material (0/40) as a starting point.

Recycling of old asphalt

In case of old asphalt recycling, asphalt materials are released at ambient temperatures and recycled either by a mix-in-place or a mix-in-plant process.
The materials are subsequently used for the construction of bound or unbound sub-bases.
Cold mixes are suitable for asphalt containing tar.

In case of old asphalt recycling, asphalt aggregates is mixed with sand and/or a binder. The binder can be either cement or a liquid in the form of a bituminous emulsion. A combination of cement and a liquid binder is used as well. In addition to these binders, asphalt aggregate can also be stabilised with blast furnace slag or fine (steel) slag.

Unbound material

Unbound aggregate is used in paving when widening road, on dams and low-load parking lots. Use in milling material is particularly suitable because of the high bitumen content resulting in a certain degree of binding. Asphalt aggregate without additional mixing is not suitable as a sub-base material because the material cannot be properly compacted. Processing is possible if approximately 25% sand is added to the material.

Emulsion-bound asphalt aggregate

Bitumen emulsion bound aggregate shows creep behaviour; the material deforms when subject to load. As a consequence, this material is only used for poorly frequented roads and, for example, yard pavement.

Cement-bound crushed asphalt

When bound with cement, this material produces a good sub-base. In case of a relatively low design compressive strength of 3 MN/m^2, the material with a layer thickness of 25 cm is equivalent to 10 cm thick asphalt concrete. An additional advantage compared to similar sand cement is the larger crack distance in this material.

Cement and bitumen emulsion bound aggregate

When bound with a combination of cement and bitumen emulsion, the result is a load resistant sub-base of low crack sensitivity. This combination is highly suitable for old asphalt containing tar because of the low leaching factor of Poly Aromatic Hydrocarbons (PAH).

Recycling at high temperatures

When recycled old asphalt, the highest user value both from a technical and an economic point of view is obtained by heat generation. It results in a rearrangement of the original physical properties and chemical composition of the bitumen, the latter being the most expensive component of the asphalt mix.

Thanks to the thermoplastic properties of the bitumen binder, old asphalt can be heated to such a degree that it can again be processed as hot asphalt. By additional mixing of new material the regenerated asphalt can be raised to the required quality. Over the years, various methods of produc-

tion for hot asphalt recycling have been developed both according to the mix-in-place and the mix-in-plant procedures.
Mix-in-place means instant in situ asphalt recycling. Several systems have been developed and will be discussed in this section. For the mix-in-plant process, system have been developed on the basis of so-called 100% regeneration and of partial regeneration when the old asphalt material is used as one of the components in the regenerated asphalt.

In both cases this means that the asphalt aggregate is heated to such a degree that the binder does not over oxidize and the volatile components do not evaporate. After adding a rejuvenating substance, such as a volatile oil or, if necessary, extra soft new bitumen, the old bitumen will be reduced to the desired penetration factor and/or penetration index. The asphalt can then be restored to its original mechanical properties.

Batch mixer (Minnesota process)
In the Minnesota process, old asphalt is added to the weigh tray or mixer and recycling percentages of up to approximately 30% are made possible. The process is an attractive one because minor adjustments make every batch mixer suitable for the recycling process. The Minnesota process (in de Netherlands known as the Aduco process) uses an adjusted batch mixer. New material (sand and coarse aggregate) is heated to such a degree above normal temperature (180 °C) that the whole mix (sand, coarse aggregate, old asphalt, filler, and bitumen) reaches the desired processing temperature. The quantity of minerals and bitumen to be added is determined by means of the old asphalt composition and the desired composition and properties of the final product. The desired penetration of the bitumen to be added can be calculated after determination of the bitumen properties in the old asphalt as follows:

pen_{me} = $pen_1^a \times pen_2^b$
pen_{me} = penetration of end mix
pen_1 = penetration of bitumen-bound crushed asphalt
pen_2 = penetration of new bitumen
a and b = relative volume ratio of two bitumens ($a + b = 1$)

The old material is overheated in quantities of 15 - 25% (for instance up to 260-290 °C for mineral aggregate). After heat transfer has been completed for the most part, the predetermined quantity of fresh bitumen is added. It goes without saying that the cycle time in the mixer exceeds that of the process of preparing new asphalt (10 to 30 seconds longer). The batch mixer is adjusted by a facility for dosage and addition of crushed old asphalt in such a manner that it is not possible for the material to cake in the plant. The ratio of old to new asphalt in this process is mainly determined by the maximum permissible temperatures in the plant, the moisture content in the components and the finished product, as well as the processing temperature. This means that the percentage of old asphalt can be 20 - 30%. The functional properties determined are the fatigue characteristics of the asphalt - fatigue life and the modules of dynamic elasticity - by means of a 4-point bending apparatus and resistance against deformation. The latter is determined by a wheel track test and tested in a creep tester. The usual properties being measured are, of course, composition, voids volume, and degree of compaction, whereas bitumen properties are determined as well. Asphalt plant should have problem-free production of constant quality. That means that process parameters such as temperature and moisture content are fully controllable.

Parallel drum

The parallel drum process is a variant of old asphalt regeneration in the batch mixer of a conventional asphalt plant where asphalt is preheated prior to combining it with the new aggregate added in the mixer (the so-called Minnesota process). Preheating takes place in a separate dryer and heater drum, the so-called parallel drum. The parallel drum system overcomes the drawback of the excessively high temperatures of the new aggregate to be added in case of high recycling percentages and/or when using asphalt aggregate with a high moisture content. The high temperatures would be a prerequisite when using unheated cold asphalt aggregate in the mixer. Depending on the type of drum, asphalt aggregate is preheated in the parallel drum to approximately 130 to 170 ^{0}C. This production method makes it possible to add a quantity of old asphalt material of up to 50% or more.

Drum mixer

When using a drum mixer, the entire production process takes place in one elongated drum. The process includes drying and heating of the aggregate (stone and sand), adding asphalt aggregate, followed by adding filler and bitumen, and finally, mixing of all components. Heating takes place under the flow principle where the material flow and the flow of hot combustion gases move in the same direction. The aggregate is conducted through the drum and heated by the hot combustion gases. Bitumen is added at the end of the drum at a place where the mineral components are dry and sufficiently hot. It is possible to process more than 50% of old asphalt in the regenerated asphalt.

MARS process

This process is relatively new. MARS stands for Microwave Asphalt Recycling System and includes de-ironing and crushing the asphalt rubble to a 0/14 size. This is followed by heating to 135 ^{0}C in a countercurrent dryer drum by means of a LOW NOX burner. Further heating then takes place by microwave in a second drum. Finally, a small quantity of rejuvenating oil is added. This method results in high percentage of recycling and very low air emissions.

Finfalt process

In 1995, a new method to prepare asphalt mixes using bitumen emulsion or cement as a binder, was introduced in the Netherlands. This process is based on a method developed in Finland. A mobile plant treats the material. The bitumen emulsion is produced on site immediately prior to dosage. Temperatures during manufacture are approximately 90 ^{0}C, heating to the required mixing temperature is done by means of steam. This plant processes 100% asphalt aggregate in mixes. Thus the preconditions are met to convert asphalt aggregate containing tar in an acceptable manner into a high-grade product. This product has been given the name Finfalt.

The advantage of this type of recycling of asphalt aggregate containing tar can be summarised as follows:

- the aggregate is heated by steam, which fully condenses in the aggregate, whereby emission is impossible.
- Poly Aromatic Hydrocarbon mobility by adding an emulsion (with or without cement).

Asphalt obtained through this process can again be used as an asphalt layer in road construction because it has retained its original properties (those of bitumen). Moreover, the material stays within the material chain.

In situ regeneration at high temperatures (surface regeneration)
The term 'surface regeneration' refers to all techniques where asphalt in the road is heated to a depth of several centimetres below the surface and is subsequently processed again in situ. If top layer processing is limited to heating (using infra-red heaters), turning up, spreading again, and compacting, without adding new material, this is called 'reshaping'. The heated and up-turned layer may be blended with asphalt chips (possibly pre-coated) to improve its flatness.
If the heated and turned up layer is blinded with chipping (possible pre-coated) to improve roughness we call it 'regrip'. This method can be used to improve flatness and roughness. When using the 'repave' process, an additional layer (maximum several centimetres thick) of new material is applied on the heated and turned up layer. This method is not only used for the entire width of the road, but also for the filling of vehicle tracks, for instance. A fourth type of surface regeneration entails gathering the heated and turned up layer in a machine, mixing it with a new mineral possibly a binder or regenerator, immediately followed by processing. This process is called 'remix'.

Successful application of any one of these methods requires satisfying two basic conditions:

a. the thickness of the layer to be treated must not exceed 0.04 m;
b. the entire construction below the layer under treatment must be in suitable condition for further use.

Remix is suitable for the manufacture of highly porous asphalt concrete with a 20% voids volume that meets the water permeability requirement by adding 30% to 70% milled highly porous asphalt concrete whilst adding bitumen 270/330 (final bitumen content 5.5%).

When using reshape, regrip or repave the old top layer, especially with regard to its mechanical properties, must be suitable, moreover, for further use. Asphalt paving that show fraying, insufficient roughness or creaking can be considered especially for surface regeneration.

Especially in the case of repave, very careful temperature control is important; only with sufficiently high temperatures can a bond of such strength come about between old and new material that one can actually speak of on layer. For all methods, it must be considered that in order to prevent bitumen ageing the temperature is bound to an upper limit. Many countries have experimented with surface regeneration.

The operating procedure is, however, relatively complex and its execution is critical as a consequence. Insight into the durability of road surface regenerated by these methods of the road surface production consumes a lot of energy.

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