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SUSTAINABLE MAINTENANCE OF ROADS USING COLD RECYCLING TECHNIQUES (SMART PROJECT)

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ABSTRACT

Recycling of existing pavement materials, and the re-use of alternative aggregates, has become an increasingly important factor in the UK for maintenance of highways. The 'linear quarry' concept of using the existing highway as a source of road-stone aggregates has gained considerable favour in recent years following the introduction of the first nationally consistent guidelines in the UK in 1999. Since that time, sustainability and environmental issues have continued to receive more attention which has resulted in the demand to consider recycling in the maintenance of a larger proportion of the primary and secondary road network. In situ and ex situ (plant mixed) variants of cold recycling techniques are now feasible and many large and specialist contracting organisations can offer these services, with the benefit of reduced consumption of energy, fuel and materials. This project, based upon a three year programme of work, provides an end-performance based design guide and specification for cold recycled materials, no matter how they are produced, and covers a wide range of cold-mix recycled materials involving a range of binders and binder blends. Materials are classified into families, which enables materials produced with new binders or combinations of binders to be introduced with relative ease. Advice is given for a wide range of traffic conditions ranging from the lightly traffic roads to heavily trafficked trunk roads. The pavement designs utilise 1-year material properties, thus enabling slow curing materials to be used in an equivalent manner to traditional materials. The specifications and advice should facilitate more prudent use of natural resources and assist in the protection of the environment.

KEY WORDS

Recycling, sustainable, cold-mix, end-performance, slow curing.

Key, words, recycling, symposium, pavement, environment

INTRODUCTION

Recycling of existing pavement materials has become, and is, an increasingly important factor in the UK for maintenance of highways. Use of the 'linear quarry' concept of using the existing highway as a source of roadstone aggregates has gained considerable favour in recent years with the introduction of the first nationally consistent guidelines in the publication by Milton and Earland (1). This report gave design guidance and specifications for in situ recycling using either foamed bitumen or cement for traffic levels up to 20 million standard axles (msa).

Since that time, increasing use has been made of binder blends and cold recycling using the plant mixed (ex situ) process which allows for screening and crushing of aggregates, prior to mixing with binder(s) in plant located nearby and laying of materials in one or more layers using a paver. In addition, the ex situ process allows the use of alternative aggregates from sources other than the existing pavement.

The SMART (Sustainable MAintenance of roads using cold Recycling Techniques) project described in this paper was aimed at 'end performance' and it sets out design guidelines and specifications applicable to both in situ and ex situ recycling techniques, although to ensure durability it has still been necessary to maintain some 'method' type elements in the specification clauses. Materials have been divided into families based upon the binder or the binder blend being used in the construction.

Proposals are included for pavement designs with heavy traffic, although it is stressed that this is an extrapolation of current knowledge of these materials and these designs should be applied with caution until further knowledge can be gained on their performance. The designs should provide for more prudent use of natural resources and protection of the environment in line with Government Policy.

The guidance is based upon a three year programme of work in which a detailed study was made at several sites during construction and for the first year following construction for a range of material families and construction methods so that the curing characteristics of each material family could be determined. Relationships between laboratory prepared samples and curing regimes and one year properties from site have also been assessed. A full account of the research carried out in the SMART project is published in TRL Report 611 (2).

SUSTAINABLE CONSTRUCTION PRACTICES

The need and desire for change to the methods and materials used for construction and maintenance has accelerated in the last 10 years. The major instigator was the Rio Earth Summit in 1992 (3) that elevated sustainable development to the forefront of government policy. The UK Government definition was developed as "…a better quality of life for everyone, now and for generations to come"; with a number of key elements including protection of the environment and prudent use of natural resources.

The UK Government objective for our transport system is that it should provide the choice, or freedom to travel, but minimise damage to the environment. Design, construction and the way in which materials are specified is changing to allow for innovation and alternatives to the use of primary aggregates. For instance, specifications can be based upon performance rather than made to strict recipes, and design procedures can be introduced to permit many options to be considered rather that do not limit the choice to new materials. In situ and ex situ variants of hot and cold techniques are now all feasible and many large and specialist contracting organisations can offer these services. Cold recycling can contribute to a reduction in energy, fuel and material consumption. The lower mixing temperatures reduce the energy required to produce these materials compared to conventional hot bituminous materials.

The wide range of recycling existing pavement materials available for construction may have properties that are different from primary materials, and this difference affects their engineering behaviour. In many cases, these properties can be turned to advantage to create new materials that have no traditional analogues. For example, pulverised fuel ash or blast furnace slag (granulated or ground granulated) can be used as hydraulic binders. In other cases, alternative materials may be used in place of primary materials. Alternative materials that can now be readily used in highway construction include: recycled construction and demolition material, asphalt planings, pulverised fuel ash, china clay sand, slate aggregate, steel and blast furnace slag, colliery spoil, incinerator bottom ash, crushed glass, recycled tyres and recycled plastic.

COLD RECYCLED MATERIALS IN PAVEMENT CONSTRUCTION

Provided that the cold recycled materials can achieve the desired performance, the potential use of cold recycling is not limited. However, each site needs to be evaluated for the most appropriate maintenance in terms of:

- Location;
- Proximity of suitable location for setting up ex situ plant;
- Proximity of source(s) of alternative materials, if required;
- Type(s) and severity of deterioration;
- Extent of deterioration;
- Location of services within the pavement construction;
- Condition of drainage; and
- Edge detail and verge condition.

The SMART (2) design guide covers all material types of cold recycled material and both in situ and ex situ construction processes. In order to adequately consider this wide range of materials, definitions of the material families are required. A versatile design methodology is also necessary to permit these materials to be used. However, the stabilising agents are likely to be the dominant component in terms of the overall performance characteristics of a given mixture. Materials bound with Portland cement are expected to cure more quickly than materials with other types of hydraulic binder, and visco-elastic materials are likely to be less prone to shrinkage cracking than hydraulically bound materials. It is, therefore, practical to define material families based upon the characteristics of the stabilising agents.

A ternary diagram, based on three distinct material types, can be used to classify materials into families, as shown in Figure 1, with the apexes corresponding to hydraulic bound, visco-elastic bound and unbound material. Recycled materials using combinations of binder and curing behaviour can be characterised by areas within this chart. Four material types that fall into three material families are illustrated on this chart. These are classified as follows:

- Quick Hydraulic (QH) with hydraulic only binder(s) including cement;
- Slow Hydraulic (SH) with hydraulic only binder(s) excluding cement;
- Quick Visco-Elastic (QVE) with bituminous and hydraulic binder(s) including cement;
- Slow Visco-Elastic (SVE) with bituminous only or bituminous and hydraulic binder(s) excluding cement.

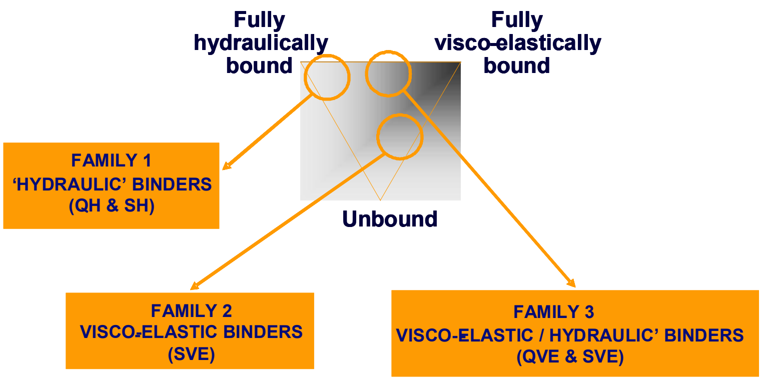


Figure 1. Identification of material families.

The performance of different types of cold recycled materials were evaluated in a number of site trials; a total of eight trial sites were visited and thirteen different mixtures were assessed covering each of the material classes. The trial sites ranged from lightly trafficked country lanes to heavily trafficked trunk roads. At all trials sites, a significant improvement in the extraction of core samples was seen using the air-flush coring technique; previous studies had encountered difficulties in routine core extraction. The improved coring success impacted greatly on the direction of the project and ultimately the method of specification. Earlier specifications relied upon non-destructive performance tests to provide assurance of the material properties; however the results of the SMART project enabled a return towards more traditional laboratory testing which could be linked to the mix design stage. The link between mix design and site compliance provides assurance to both the Client and the Contractors and allows the Contractor to manage the cold recycling works more effectively.

PAVEMENT DESIGN INCORPORATING RECYCLED MATERIALS

The current UK pavement design standard (4) dealt only with hot mix asphalt and cement bound material in a restricted range of design options. To enable recycled materials to be used, its versatility had to be to be increased to give the highway engineer a wider choice of materials. To achieve this, a parallel project was embarked upon to modify the design method to help to deliver environmentally-friendly design solutions. To achieve this, the current design methodology has been followed as much as possible to minimize disruption that would result from a radically new method. The new approach (5) continues to rely upon current test methods and material properties. The method allows new materials, recycled materials and a wider range of secondary aggregates and binders to be used.

Generally, the materials properties identified by Powell et al (4) are retained with the exception that the design values are those that are achieved after 360 days in service. This will enable slow curing recycled materials to be more readily incorporated. The new design approach also enables stronger classes of foundations to be used that will enable the full potential of the foundation layers beneath the recycled layers to be used in the overall pavement design. The foundation stiffness classes are defined in terms of the equivalent half-space stiffness of the composite foundation. The following four divisions, described in more detail are defined:

- Class 1 ≥ 50 MPa;
- Class 2 ≥ 100 MPa;
- Class 3 ≥ 200 MPa;
- Class 4 ≥ 400 MPa.

The standard UK foundation (equivalent to 225 mm of Type 1 sub-base on a subgrade with a CBR of 5%) will correspond to Class 2. The Class 1 foundation is applicable to construction on a capping layer and Class 3 and 4 foundations will involve bound sub-bases.

SMART DESIGN GUIDE

The following flow diagram illustrates the various stages of recycling described in the design guide (2).

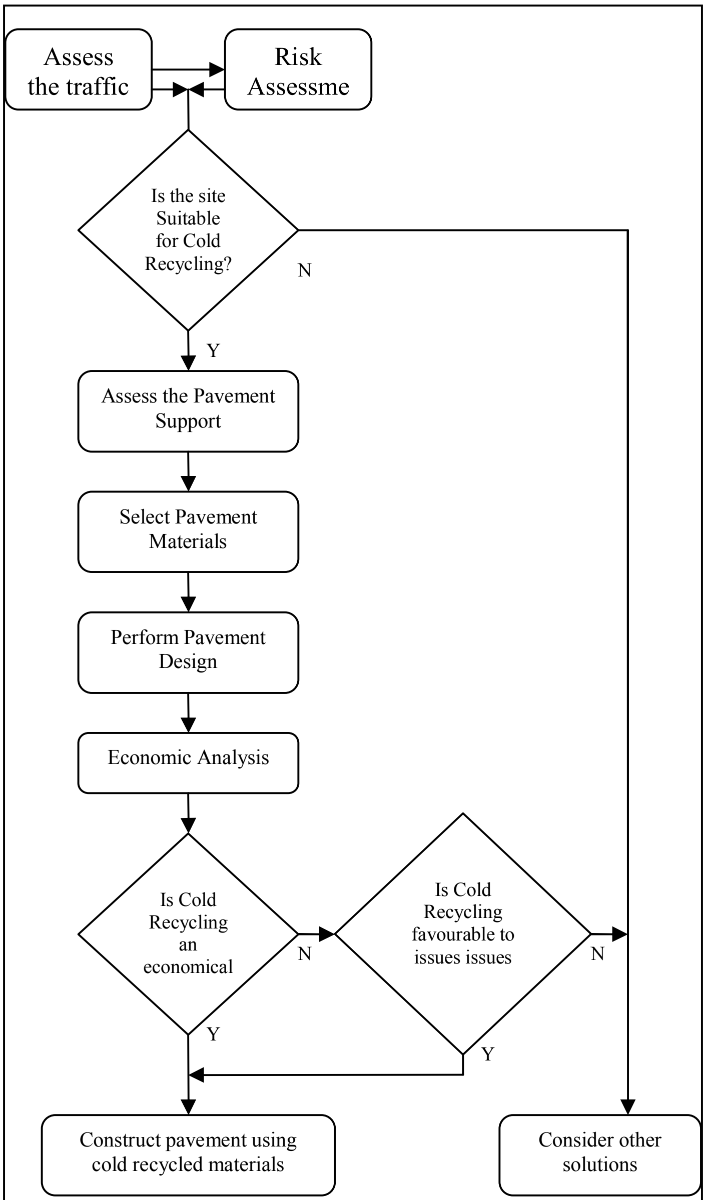


Figure 2. Stages of recycling

Site Evaluation

The site evaluation needs to consider:

Assessment of pavement deterioration

A site may be identified for maintenance following an assessment of the pavement condition. Where structural maintenance is required, or replacement of the binder course layer, a rehabilitation treatment of the pavement using cold recycled pavement materials can be considered.

Traffic assessment

A pavement containing recycled materials must be designed so that it can carry the traffic over the whole of the design period. Traffic is generally be described in terms of a cumulative number of equivalent 80 kN standard axles. The road categories defined in terms of million standard axles (msa) in Table 5.1 are used to describe the pavement design options for pavements comprising cold recycled materials.

Table 5.1 Road type categories

Road type category	Traffic design standard (msa)
0	Roads carrying over 30 to 80* msa
1	Roads carrying over 10 to 30 msa
2	Roads carrying over 2.5 to 10 msa
3	Roads carrying over 0.5 to 2.5 msa
4	Roads carrying up to 0.5 msa

* Road type category 0 has been restricted to 80 msa in this guide

For each of these road categories, different levels of risk can be assigned. For the road categories carrying the heaviest traffic, the risk of failure should be minimised. However for the lighter traffic categories, a higher risk can be accommodated. The pavement designs for Type 0, 1 and 2 roads have been produced according to a design methodology analogous to that which is implemented in the *Design Manual for Roads and Bridges* (6). For Type 3 and 4 roads, there are permitted variations in the core design methodology that balance an increased risk of failure with more economic pavements incorporating cold recycled materials.

Evaluating the Suitability of Cold Recycling Treatments

The suitability of cold recycling treatments depends on many factors. The chief criterion will be economic. However, if cold recycling treatments are uneconomic compared to treatments using conventional hot mix materials, the case for cold recycling may still be viable provided that there is an appropriate policy for cold recycling treatments as part of a wider sustainability campaign.

The economic analysis of cold recycling should be based on a whole life cost approach that includes the present cost of the treatment as well as all other discounted future maintenance costs associated within a specified analysis period. In order to compare with conventional treatments, a default analysis period should be 30 years although longer periods could be selected dependent on the local policy or the nature of the treatment.

Assessment of Pavement Support for Full Depth Recycling Treatments

The design of a pavement containing recycled materials is affected by the quality of support provided by the layer below the recycling treatment. Weak support may necessitate a high quality or thicker material to be placed. The intrinsic support offered to the pavement is one factor of the design that should be provided to the pavement designer.

The pavement design procedure for superior roads (road types 2 or greater) requires that the foundation is classified into one of four classes defined earlier. The foundation classes are an integral part of a versatile design methodology that was developed (5).

Three main avenues for the assessment of the support under a proposed recycling scheme are available to the designer; these are a desk-based records study, invasive assessment and non-destructive assessment. It may be advisable to augment a desk study with some limited investigation to confirm the quality of the construction records.

Assessment of the suitability of materials from an existing pavement

The assessment of the suitability of materials in existing pavement structures will only be required if the cold recycled materials will contain aggregate from the existing structures. Where required, the assessment is likely to be carried out at the same time as the assessment of pavement support. Otherwise, an alternative method of obtaining representative material for the assessment should be investigated such as a limited coring survey.

Risk Assessment

The use of cold recycling techniques for pavement maintenance involves particular risks that may not be encountered with other types of maintenance. The likely risks associated with cold recycling need to be considered so that they can either be mitigated or accommodated. Site specific and material specific risks will be encountered which will need to be considered prior to commencement of the works. These risks are often difficult to quantify in terms of any standard measure, but their consideration and equitable allocation will be vital if the cold recycling operations are to be completed to the satisfaction of both contractor and client. Ignorance of these risks could lead to economic losses and/or a poor product.

Risks can be broadly classified into design risks and construction risks. The design risks are associated with the pavement design in terms of the expected performance on the structure and mix design risks in terms of the expected performance on the recycled material. Construction risks are encountered during the preparation of the site for laying recycled materials as well as the production, transporting and laying of recycled material.

Pavement design risks

Pavement design is the process of selecting materials and construction thicknesses in order to ensure that the pavement structure will carry the expected traffic for a given period of time. It relies upon the assumption that the construction process will provide expected long-term properties of the material in layers that are of sufficiently thickness. A comprehensive site investigation needs to be carried out to minimise the risks in the calculated pavement design, including a detailed subgrade study.

Mix design risks

Mix design is principally performed as an essential input to the pavement design process. As such the risks for mix design will have a significant impact on the risks associated with pavement design.

The recycled aggregates from existing roads containing multiple layers may be more variable in quality and type than those from a single layer. Where possible, the mix design stage should take into account this variability by varying the proportions of recycled aggregate from each layer.

Construction risks

Construction of a pavement comprising cold recycled materials is dependent on a large number of linked processes.

The compaction of cold recycled material is one of the most critical parts of the construction procedure; it is influenced by the duration between mixing and laying of the material and the selection and use of compaction plant. The Contractor needs to be aware of the workability of the material and manage the construction processes so that delays are minimized. Delay after mixing the material or poor selection or use of compaction equipment may lead to a substantial loss of serviceability of the finished pavement due to reduced levels of compaction.

Other risks include:

- Slow curing materials take time to achieve their potential; construction issues and the local environment can affect the time required for the material to gain sufficient mechanical stability or strength and the speed of opening to traffic is a consideration.
- Nuisance and possible risk to health by dust during any pulverisation process and the effect of plant on the surrounding environment needs consideration.
- The risk to underground services and existing road furniture needs to be considered and also the existing road geometry, kerbing, situations where there is restrictive headroom, etc.

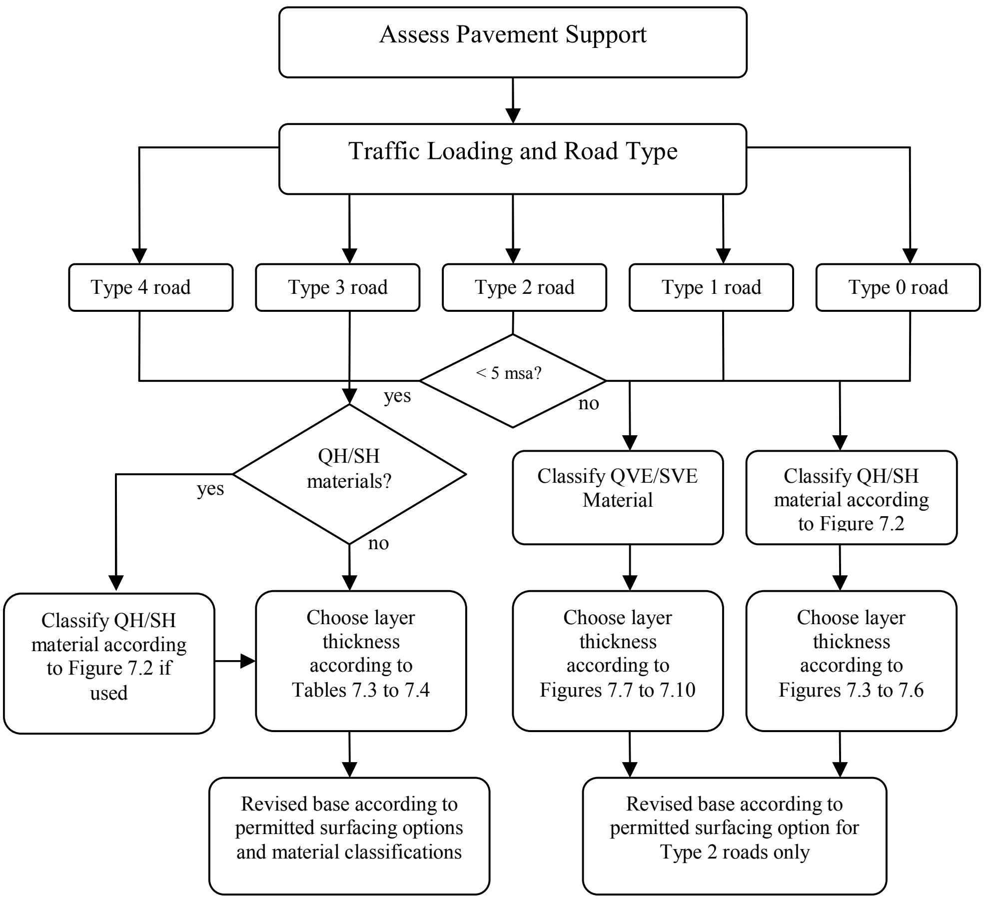
MIX DESIGN OF COLD RECYCLED MATERIALS

Many of the materials that could be considered to be cold recycled materials are described under the umbrella of European (CEN) standards. It is, therefore, prudent to ensure that the grading used for the specification to cover cold recycled materials is consistent with the all materials in the CEN standards that are likely to be required to be covered by this guide.

The mix design has to consider:

- Aggregate grading;
- Moisture content;
- Binding agents;
- Selection of materials;
- Mix appraisal and design;
- Laboratory studies.

Pavement Design using Cold Recycled Materials
The design of pavements comprising cold recycled material follows the versatile pavement design methodology (5). This method uses a single pool of input data from which separate design criteria are applied depending on whether the base comprises a hydraulically bound or bituminous bound material. The Figure below gives an illustrative view of the pavement design



process for cold recycled materials.

Figure 3. Full depth pavement design process for cold recycled materials

SPECIFICATION OF COLD RECYCLED MATERIALS

Specifications for the production of cold recycled materials have been covered in the Highways Angency's *Specification for Highway Works*. These specifications have covered the production of cement bound and foamed bitumen bound recycled material using in situ stabilisation. In recent years, ex situ cold recycled material technology has evolved and there is increasing demand for a wider range of materials to be covered by a publicly available specification.

The over-arching concept of this specification is to have one single specification document to cover the whole range of cold recycled materials which will improve the procurement of the diverse range of cold recycled materials available. The components of cold recycled materials covered by this specification include:

- Bitumen emulsion
- Foamed bitumen
- Cement
- Granulated blast furnace slag (GBS)
- Ground granulated blast furnace slag (GGBS)
- Lime
- Pulverised fly ash (PFA)
- Unweathered Basic Oxygen Slag (BOS)

The specification has been designed to focus on the quality control of the material and to ensure that proposals for end-performance made at the mix design stage are achieved in the permanent works.

Two specifications have been developed: one for the ex situ process and one for the in situ process. The division of the specifications has been done for means of clarity only. The structure and requirements for the materials in each specification are identical. The procurement of cold recycled materials should not be biased towards either specification instead the choice of process should primarily be an economic one. The specifications include end-product performance tests of the material where rationally possible. The notes for guidance gives more advice on end-product tests and other best-practice approaches to quality control.

Quality plan

The quality plan forms the core of the specification for cold recycled materials. It is a document that is prepared by the Contractor and agreed with the Client and covers the entire life cycle for the production of the cold recycled materials from the mix design stage through to the end-product testing stage.

The specification does not prescribe the entire content of the quality plan although there are some mandatory minimum requirements. Instead, the contractor is provided with significant freedom to produce a material quality plan that satisfies the Client whilst ensuring economic efficiency.

Mix Design
The aim of the mix design process is to provide assurance that a cold recycled mixture will have the appropriate properties one year after constructions. The selection of one year properties is to encompass slow curing materials as prescribed by the pavement design method.

Method Statement
The method statement comprehensively describes the process of producing and laying the material. It includes:

- ***The sources of recycled components.*** The method statement shall include as full a description as possible of the composition of the components to be used in the cold recycled material. It also covers the size of the available stock of the components and an indication of the reliabilty of the source of material. For in situ stabilisation, the method of pulverisation shall be stated.
- ***Production.*** The method of production of the cold recycled materials shall be described. The storage of the component materials may be important to maintain the quality of the product material. The plant used for mixing the components shall be detailed including the method of adding and controlling the components.
- ***Transportation to site for ex situ process.*** The location of the mixing plant shall be declared and details of transportation of material to the site and the anticipated duration between the mixing and compaction. A risk assessment for possible delays shall be performed.
- ***Laying and compaction.*** The plant used for placement and compaction of the cold recycled mixture shall be described together with quality control measures that will be undertaken at the site should. The procedure for laying the material should also cover early life trafficking issues. In early life there maybe a risk of over-stressing the material and forming cracks in the material and unduly damaging the recycled material.

Process Control and End-Product Criteria
The specified process control procedures need to be designed to be generally consistent for all types of cold recycled material covered under the specification although there are permitted variances for certain tests. Overall, the specified process controls cover:

- Moisture content
- Batching checks
- Degree of compaction
- Structural performance
- Thickness

The moisture content is monitored so that the material immediately prior to compaction is within 2% of the optimum moisture content for compaction. The proportions of the binding fractions are also monitored by the batching checks; more stringent compliance targets have been placed on bituminous fractions than other hydraulic fractions. The degree of compaction is monitored using relative in situ density as measured using a Nuclear Density Gauge operated in direct transmission mode with an average limit of 95% of refusal density being specified.

The specification focuses on the adherence to stated performance characteristics in the quality plan (QP), as defined in the mix design process. Material sampled from the mat prior to compaction is then subjected to an identical sample preparation and laboratory curing and testing regime as was declared for the job site mix in the QP; the values of stiffness and strength obtained from the process need to satisfy the same criteria as defined in the mix design stage. Where superior performance has been used as a basis for adjusting the pavement design, the results of the process control tests shall also be compared to the design values.

All the specified process control criteria are minimum permissible values. There is an opportunity for the Contractor to demonstrate adherence to superior process control procedures using the appropriate sections of the quality plan.

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