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*DOI:*
10.17265/1934-7359/2022.01.004



*Citation for published version (Harvard):*
Endale, A, Ghataora, G & Burrow, M 2022, 'Asphalt pavement cold recycling and basic characteristics of RAP materials and their application', *Journal of Civil Engineering and Architecture*, vol. 16, no. 1, pp. 38-51 .
https://doi.org/10.17265/1934-7359/2022.01.004

Journal of Civil Engineering and Architecture 16 (2022) 38-51
doi: 10.17265/1934-7359/2022.01.004

# Asphalt Pavement Cold Recycling and Basic Characteristics of RAP Materials and Their Application

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**Abstract:** In the developed countries significant proportion of reclaimed asphalt pavement (RAP) materials are used in the construction of pavements. Until recently, milled asphalt from old roads was sent to tip as waste. However, in recent years there has been increased use of waste materials in many road projects within the capital city and federal road network. Use of RAP materials is relatively new to Ethiopia and understanding its characteristics and related technology with all its potential environmental, economic and social benefits is important. Cold recycling is desired due to its potential economic benefit. In this study characteristics of RAP materials are assessed both from literature and laboratory investigations in order to better understand its performance and use. Questionnaire survey was undertaken to identify factors that are hindering recycling of materials in pavements in Ethiopia and what is to be done to overcome these factors. A policy statement is derived to support a quick start and implementation of asphalt pavement recycling in Ethiopia. Currently, a huge asphalt pavement network is being constructed and virgin construction material exploration and import materials such as bitumen is costing the country a lot of money. Over USD 7 Billion worth asphalt pavement have been constructed over the last 23 years to serve the public and freight transport, which requires about USD 176 million annually for maintenance and rehabilitation works. Therefore, any saving obtained from recycling will have meaningful impact on cost saving and environment preservation.

**Key words:** RAP, recycling, binder, aggregate, policy, CIR, cold in-place, FDR.

## 1. Introduction

Aggregates sources from natural sources such as rock and sand are non-renewable and will deplete by continued extraction compromising their use by of future generations. Generally, the production and transportation of new materials also utilize heavy machineries for extraction and haulage, both demanding high energy input and have significant impact on the environment. Use of traditional, virgin materials, make our roads non-sustainable and environmentally unfriendly.

To minimize use of aggregates based on virgin materials and bitumen, reduction of energy demand, and minimize environmental damage, alternative methods of rehabilitation of roads were sought for application in Ethiopia. Accordingly, a questionnaire-based study was undertaken. This was followed up by a laboratory investigation and development of a draft policy framework to facilitate implementation of the technologies for using RAP materials in road construction. Key findings of these studies are described in this study. A systematic literature review method was also applied where research question was formulated, key words identified and various search engines used to extract information and finally systematic analysis of obtained information carried out. The outcome these works is finally presented in this work and it can be concluded that it is possible that properly designed and constructed RAP material in pavement can produce a pavement that as good as one constructed using virgin materials [1]

### 1.1 Method

The research work was planned and carried out by applying the following methods:

1. Systematic review of recycling of asphalt pavement materials;

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2. Questionnaires and interviews to identify viability of using RAP materials;

3. Laboratory testing to identify properties to confirm viability of using RAP materials in Ethiopia;

4. Development of draft of policy framework.

## 2. Findings of the study

### *2.1 Types of Asphalt Pavement Recycling*

One of the key questions that needed answering was about understanding the type of Asphalt Pavement Recycling methods currently available. Different methods of asphalt pavement recycling are applicable to different types of input materials (RAP), extent and severity of pavement damages which also relate to different periods in the pavement life [1]. Old asphalt can be recycled using cold, warm and hot production methods and can be performed either in the plant or on site [2]. Classification of pavement recycling methods can be done in two ways [3]. The first is by location as in-plant or in-place and the second by the extent to which the reclaimed materials are heated as cold (below 70ºC), warm (between 70ºC and 120ºC) or hot (above 120ºC). This classification system is shown in Fig. 1.

Through systematic review of literatures, Analytic Hierarchy Process and questionnaire three methods suitable for Ethiopia were selected. All of them were cold recycling approaches and are Cold In-Place, Cold In-Plant and Full Depth Reclamation. The main issues envisaged were s the behavior of reclaimed materials and expected performance of RAP mix. Accordingly, detailed assessment through literature review and laboratory investigation was carried out to investigate performance and behavior of RAP.

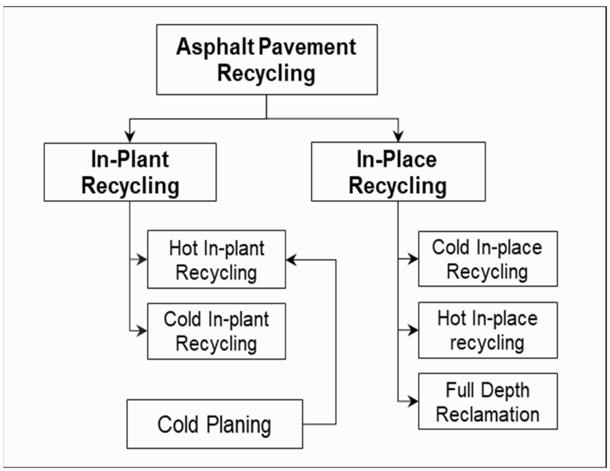



**Fig. 1 Asphalt Pavement Recycling classification.**

### *2.2 Cold In-place recycling (CIR)*

CIR is a process that uses cold milling of the surface and remixing with the addition of asphalt emulsion, Portland cement, foamed asphalt, or other additives to improve the properties of the RAP, followed by placing and compacting the new mix in one continuous operation [1]. CIR has minimum environmental impact, energy saving and has economic benefits that makes it desired recycling technique. 30% of the literatures examined show that CIR is environmentally friendly method. $CO_{2eq}$ reduces by 18kg or 35% per ton compared to virgin mix [4] while another study claims that the reduction of CO2 can be up to 52% (Shatec engineering, 2013). It has minimum GHG emissions and reduced Global warming potential. Reduction of Global warming by 20% and waste material by 6% is also advantage of this method [5]. It is also economically sustainable and reduces use of virgin material compared with traditional rehabilitation methods. Most of the savings are associated with the significantly reduced need for hauling materials, waste disposal to landfills and minimized use of virgin materials. By using CIR cost saving of 30 to55% can be achieved [5, 6].

Benefits of Cold In-place recycling are summarized as follows [6-8]:

1. It helps to remove surface irregularities, stop crack propagation, and eliminates rutting and corrugation;

2. It uses 100% of the RAP material on the same road pavement which avoids the removal transportation and stock piling process there by reducing cost and emission problems;

3. Economically sustainable as it avoids the production, processing, transportation and laying of virgin asphalt;

4. Conserve energy as it eliminates the transportation of virgin material to central plant and to the work site;

5. Base and sub-base materials are not disturbed as the recycling is mostly limited to the surfacing material;

6. Improve safety by reducing traffic disruptions, and user inconvenience whereby economic savings are realized.

CIR is simple in terms of the concept; however, a number of specialist machines are used in the process. Process starts with the use of a specially designed powerful machine, that has a drum with strong cutting bits for milling and pulverization of existing pavement [9]. This is linked to a recycling machine where the granulated pavement material is mixed with binding agents and water to produce a homogeneous mix that is used for repaving. This process is fast and takes place in one operation of rehabilitation of pavement.

### *2.3 Cold In-Plant Recycling*

Cold-mix recycling generally refers to central plant mixing and done without heating the materials [6]. Material from the road is stock pilled in a central location and is processed and used in the plant for mixing which is important for quality and homogeneous mix result [9]. The process is similar to as the hot central plant mixing, except it does not involve any heating, and therefore emulsion bitumen is used as a binder in most cases. The main benefits of Cold In-Plant recycling are the control over the input material, quality of mixing and stockpiling capabilities [9]. It can also reduce the cost of rehabilitation by 40 – 50% [6] and highly advantageous if locations where RAP material can be stockpiled is available. The key advantages of Cold in-plant recycling are listed below:

1. It can generally utilize 100% of RAP material produced from existing pavements;

2. Enables the conservation of non-renewable resources and energy;

3. Allows for proper selection of new granular materials and stabilizing agents;

4. Avoids waste disposal by collection and processing RAP material in a central plant;

5. Allows the correction of mix problems in the existing pavement through re-grading aggregates by adding proper sizes of virgin aggregates and using appropriate new binder.

The equipment for placing and spreading the mix to form the pavement is generally the same as for conventional hot mix asphalt [6].

### *2.4 Full Depth Reclamation (FDR)*

FDR is the rehabilitation technique in which the full thickness of the asphalt pavement and a pre-determined portion of the underlying materials (base, sub-base and/or sub-grade) is uniformly pulverized and blended to provide an upgraded homogenous base material [7]. This type of recycling technique for pavement construction and rehabilitation has gained general recognition because of its technical, economic and environmental advantages [10]. In the FDR rehabilitation pavement can be milled 150 – 350mm depth, mixed with new bitumen and existing material to form a uniform and strengthened pavement structure [11]. National Asphalt Pavement Association (NAPA) also indicated that hydraulic binders are also added creating Hydraulically Bound or Cement Bound mixes (HBM and CBM) using 100% Recycled Aggregates. The main advantages of FDR are as follows:

1. Helps to conserve energy as it uses few pieces of equipment on the recycling operation;

2. Helps to correct sub-base or sub-grade deficiencies through stabilization to restore structural adequacy of the pavement structures;

3. Problems with existing aggregate gradation can be corrected with proper selection and addition of new granular materials;

4. As it is in-place method reduced traffic disruptions and user inconvenience, and environmental impact;

5. Can adjust thickness of the bound layers (both base and wearing courses) giving a wide range of wearing surface types and thicknesses;

6. Allows for the reshaping profile of the road construction layers to permit drainage;

7. Helps to eliminate surface defects as the wearing surface along with a portion of base course is recycled in a single recycling operation.

FDR and CIR have similar application and the machines used and setup are similar where in FDR the depth of cutting is extended to incorporate the underlying base layer. The operation can be carried out in different ways that varies from a multi-step to a single step process [6]. In the multi-step operation, the removal, crushing, mixing with additives, and compacting of the reclaimed material is carried out in standalone operation. The cutting can be carried out using a dozer or motor grader with ripper, and using various equipment for size reduction and pulverization. However, currently there are a variety of technologies that can combine all the different operation in to a single step. The single pass recycling machine is set up in such a way that the operation of cutting, mixing with additives and laying of reclaimed material is finished in a single machine with attachments to water and other additives feed tanker.

## 3. Recycled Asphalt Pavement (RAP) Materials

RAP Material is the term given to removed and/or reprocessed pavement materials containing asphalt and aggregates. Once the asphalt pavement material is removed and processed it becomes RAP material [12]. These materials are generated when asphalt pavement layers are removed for reconstruction, resurfacing, or to obtain access to buried utilities. When properly crushed and screened, RAP consists of high-quality, well-graded aggregates coated by asphalt cement [8].

RAP can be used in asphalt surfacing, in base and sub-base courses, and in gravel roads as a wearing course. Understanding the behavior of this material is key to its proper use in road construction and rehabilitation projects. The production, handling, and physical and mechanical properties of RAP are main concern for its application.

### *3.1 Production of RAP materials*

RAP production may not be defined well in the literatures and standards; however, they can generally be produced either milling the pavement by a machine or removed in slabs from the pavement by excavators [13]. The removed slabs may be processed in a crushing plant, fractionated and stockpiled either for cold or hot plant asphalt mixing. Cold planning process also produce RAP materials that can be used for the central plant mixing for both hot and cold in-plant recycling.

Large quantities of RAP materials are produced every year. From 2001 – 2017 over 1.8 Billion RAP material was produced in Europe (see Fig. 2), America, Canada, Japan and Australia. 46% of this is produced in the US while the production in Europe is 47%. Earlier studies also show that in the US over 90 million tons of asphalt pavement material was reclaimed in the early 1990's [12].

These materials are used for different purposes but more than 90% goes back into the road construction and maintenance. Data from NAPA shows that the RAP material is used for HMA, Warm Mix, Cold Mix and in Unbound layers. Data from 2010 – 2017 shows that RAP materials are being used extensively and this trend is growing as in recent years100% is going back into road construction.

### *3.2 Processing of RAP Materials*

According to the FHWA report [8] material processing or preparation methods vary for different recycling alternatives. RAP to be used as granular base is crushed, screened and blended with conventional aggregate (to avoid agglomeration of crushed RAP) and stockpiled. The machineries

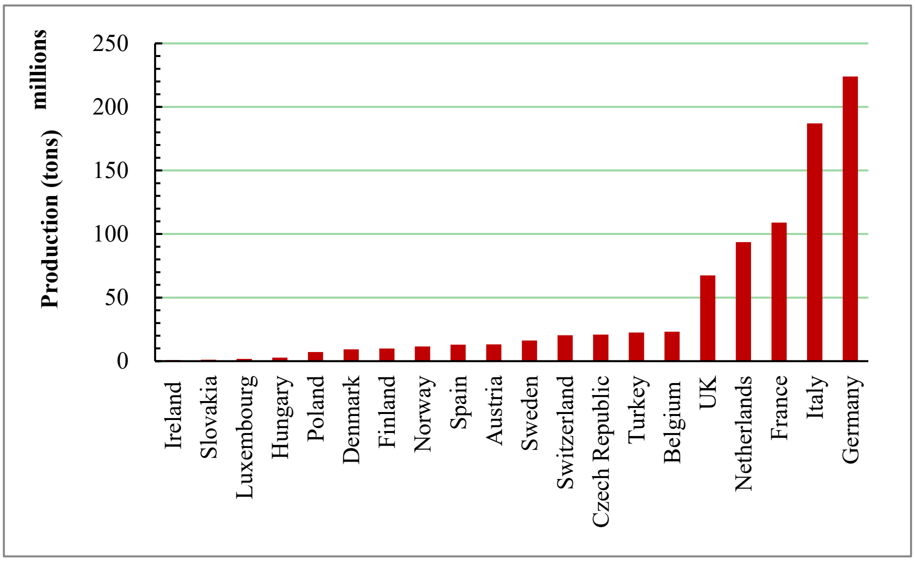



**Fig. 2** RAP production from 2001 – 2017.

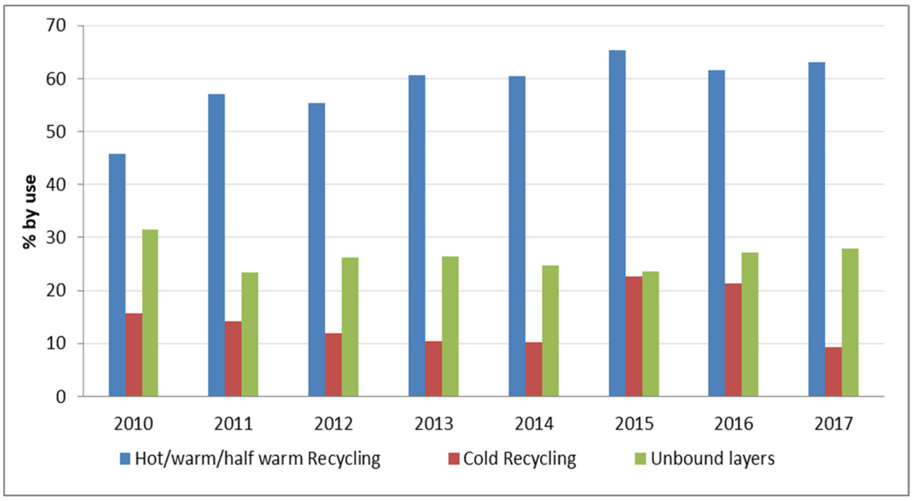



**Fig. 3** Uses of RAP materials from 2010 – 2017.

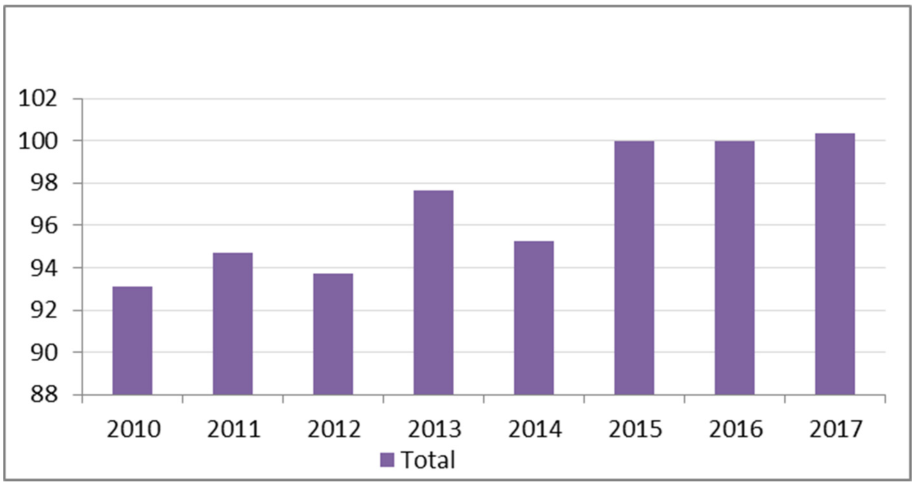



**Fig. 4** Total RAP material used back in the road.

required may also include crushers, screens, loaders and stackers. Processing of RAP is carried out to achieve the following basic goals [14]:

- Create a uniform stockpile of RAP from various different sources;
- Separate out and crush large agglomerations of RAP particles to a size that can be efficiently heated during mixing with the virgin aggregates;
- Reduce the maximum aggregate particle size in the RAP so that it can be used in surface mixes comprising small (3mm to 14mm) aggregate;
- Minimize the generation dust from crushing operation.

RAP material from a single source is processed only to reduce particle size to acceptable level, while RAP from different sources is processed to create a uniform material to achieve required gradation as well as strength, and binder properties. Therefore, care must be taken during the processing of RAP from different sources.

### *3.3 Handling/ Stockpiling Rap*

RAP produced and not reused in the same road is transported to a central stockpile location for future use. In cases where RAP (from different sources) is stockpiled care must be taken to avoid contamination and segregation as well as mixing materials of different characteristics. It is also considered as one of deterring factors not to use RAP materials in large percentages in asphalt mixtures [14]. RAP from different sources stockpiled on one site may have the advantage that during the process of crushing and screening mixing of different source materials will enable production of a homogenized material.

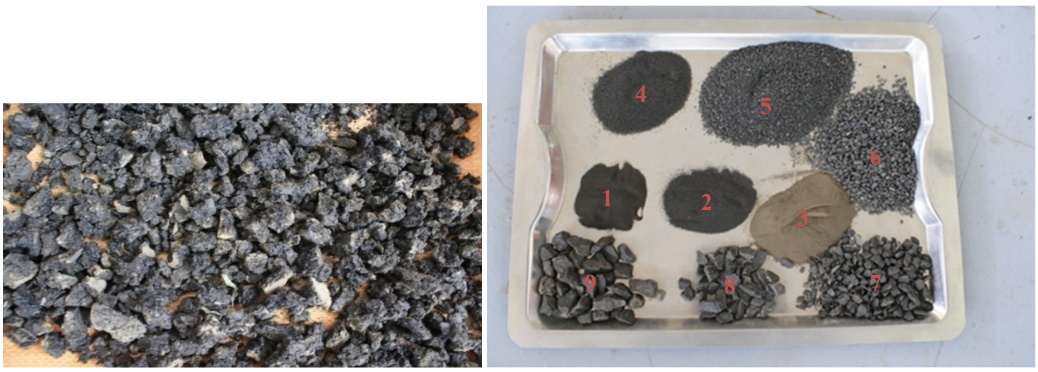
The moisture content of RAP materials in a stockpile shall be kept to the minimum to avoid the need to heat the RAP during asphalt mixture preparation. RAP in stockpile shall be:

- Free from foreign materials;
- Stored under shelter as necessary to minimize the moisture content;
- Handled using suitable machinery to avoid compaction;
- Shall routinely skimmed to break lumps;
- Stored such that segregation is prevented or minimized.

Segregation of RAP material in stockpiling is a common problem. In large stockpiles larger particles tend to roll down and accumulate at the base of the stockpile and in such cases, it is better to use front end loaders to remix the material in the stockpile.

### *3.4 Composition of RAP*

RAP material comprises aggregates and bitumen in the mix [15]. Materials in the original mix will remain combined together unless disintegrated during reclamation process. The laboratory hand crushed RAP material is shown in Fig. 5(a) and Fig. 5(b). shows different proportions of particle sizes after removing the binder




(a) (b)

**Fig. 5 RAP material: hand crushed (a) and gradation after binder extraction (b) [1 – 75µm, 2 – 150µm, 3 – pan, 4 – 300µm, 5 – 600µm, 5 – 5mm, 6 – 9mm, 7 – 12mm, 8 – 14mm, 9 – 19mm].**

### *3.5 Properties of RAP Materials*

Engineering properties of RAP materials are affected by its composition. The quality of aggregates and bitumen in RAP materials are of the main interest. The main engineering properties of RAP materials are, gradation of aggregates, amount of asphalt cement in RAP, penetration, ductility and viscosity of asphalt cement.

3.5.1 Aggregates

3.5.1.1 Physical properties

*Gradation:* Particle size distribution of RAP aggregate is dependent on the type and thickness of the existing pavement surface from which the RAP is obtained. Pavements which are overlaid at different times without removing the existing asphalt pavement may have variable aggregate sizes in different proportions According to the Wirtgen Cold Recycling Manual [9] the grading of milled RAP is influenced by various factors:

1. composition and uniformity of existing asphalt material;
2. condition of the existing asphalt material;
3. temperature of the asphalt in the milled horizon;
4. depth of milling;
5. speed of advance of the milling machine;
6. rotation speed of the milling drum;
7. type of milling drum and condition of the milling tools;
8. direction of cut (up-cutting or down-cutting).

Determination of RAP aggregates particle size distribution is important to determine the necessary amount of virgin aggregate to be added to obtain the maximum density or strength of pavements. Due to mechanical degradation of aggregates during asphalt pavement material removal and processing the gradation is finer than virgin aggregates though the RAP aggregates can satisfy the requirements of ASTM D692 and ASTM D1073 for coarse and fine aggregate requirements for bituminous pavement mixtures [8].

In Fig. 7 Gradation of recovered aggregate from RAP materials is shown. Majority of the grading curves show finer gradation in reference to grading envelope for HMA of Asphalt Institute 1994. This shows that original particle size distribution is affected during reclamation. More than 80% of the result shows that after 2.36mm sieve the particle size is outside the upper limit and are fine materials.

The deviations are more pronounced on sieve sizes 2.36mm, 4.75mm, 9.5mm and 12.5mm. Thus consideration is given to the gradation when using RAP materials and may be necessary to blend with virgin aggregates to correct the particle size distribution of the mix if used for surfacing.

Average of maximum and minimum % passing of results extracted from various literatures indicate the gradation curve fits in 12.5mm nominal size of grading limit while it is shifting to the upper limit and out of the envelop of the 19mm nominal size (Fig. 7). This indicates that gradation of aggregates is affected

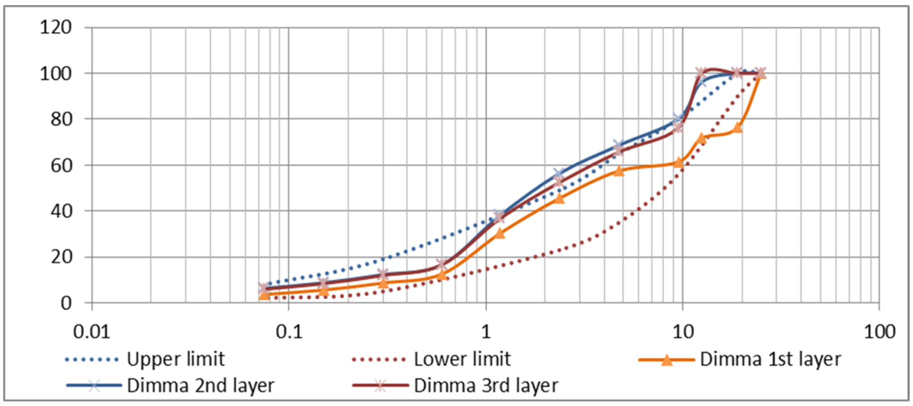



**Fig. 7 Aggregate gradation of different layers of same road.**

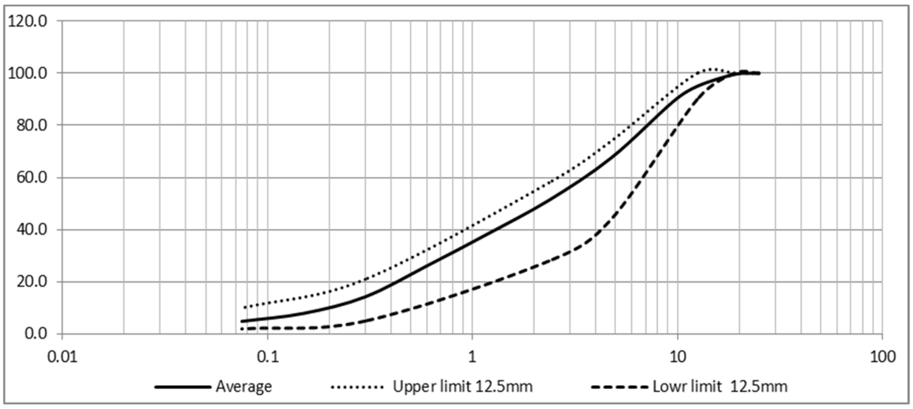



**Fig. 8 Average % pass for 12.5mm nominal size grading limits of Asphalt Institute 1994.**

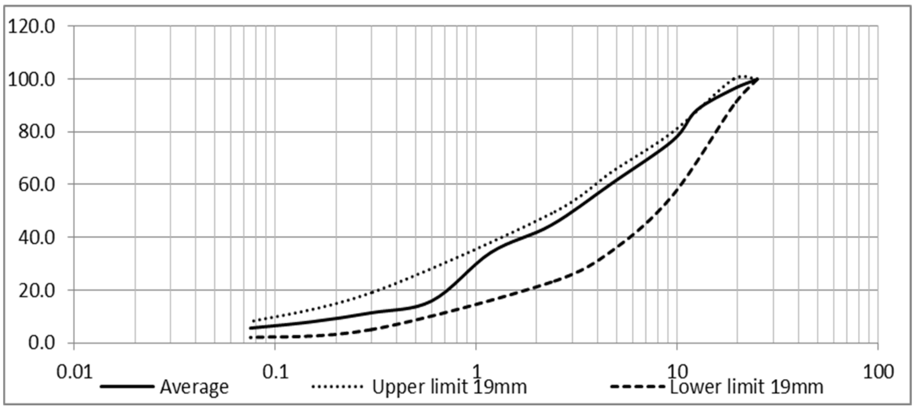



**Fig. 9 Average % pass for 19mm nominal size grading limits of Asphalt Institute 1994**

during reclamation. For RAP retrieved manually, processed and tested in lab the average % passing fits very well within the grading limit for all nominal sizes (Fig. 8). Therefore, it can be concluded that aggregates in the RAP does not change and still has high quality to be used as virgin aggregate.

As the shape and surface texture will change during reclamation, tests are conducted to check the change. With respect to the shape of RAP aggregates, Course Aggregate Angularity (CAA) and Fine aggregate Angularity (FAA) tests are conducted. The Course Aggregate Angularity is measured as one of the shape factors which is the measure of the degree of roughness and sharp angle of aggregate particles that is determined manually by visual inspection [17].

3.5.1.2 *Mechanical* Properties

Mechanical properties of RAP aggregates are considered to be same as when it was used at the first time. The properties depend on the original asphalt pavement type, the method(s) utilized to recover the material, and the degree of processing necessary to prepare the RAP for a particular application [8]. The mechanical properties are Los Angeles Abrasion (LAA), Aggregate Impact Value (AIV), Aggregate Crushing Values (ACV), and Ten Percent Fines Value (TFV). It is assumed that the Abrasion values of the aggregate obtained from recycled asphalt pavement will not change and satisfy the requirements of specifications to be reused as it was tested and allowed to be used in the first time.

Samples were collected from different locations and bitumen was extracted using the solvent method to separate aggregate from bitumen. Samples were carefully hand crushed and heated before extraction. Gradation and strength tests were conducted on samples taken from existing damaged road to evaluate if the properties of the aggregate are changed. The result shows: ACV = 10%, AIV = 8% and TFV = 336kN

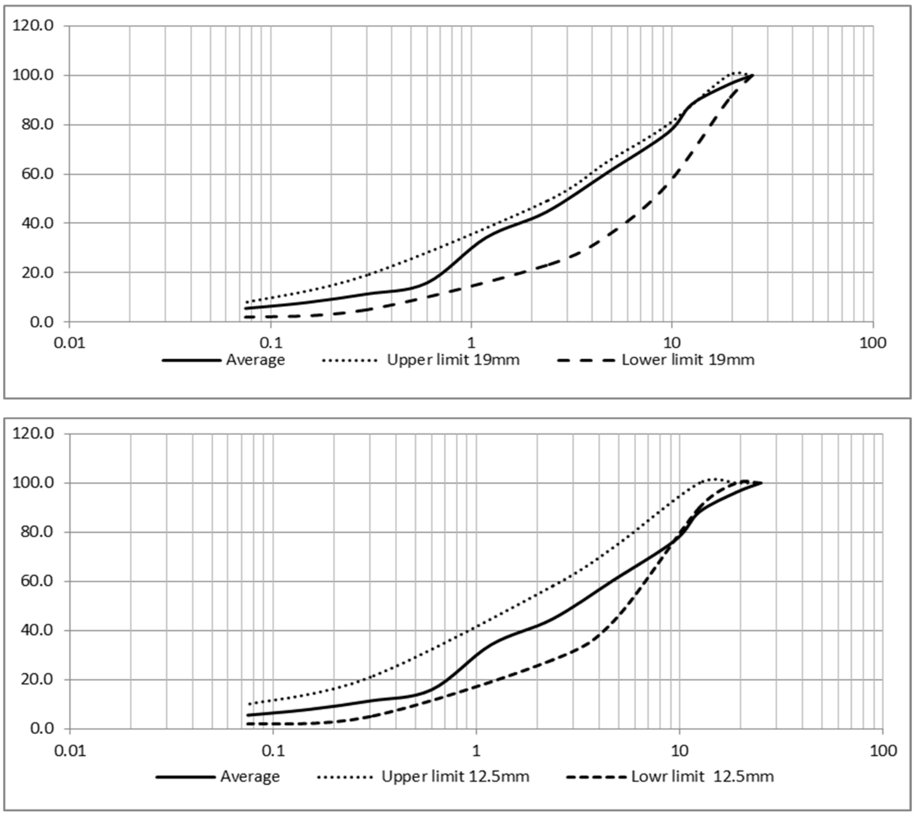



**Fig. 10 Average % passing of lab prepared sample for different nominal size grading limits of Asphalt Institute 1994**

**Table 1 Bitumen content of reclaimed asphalt.**

| Sample | Bitumen content (%) | Average | Bitumen content (gm) | Average |
|---|---|---|---|---|
| B1 | 4.02 | | 40.2 | |
| B2 | 5.5 | | 54.9 | |
| B31 | 4 | 4.87 | 60.7 | 52.75 |
| B32 | 5.4 | | 41 | |
| B4 | 4.19 | | 54.4 | |
| B5 | 6.08 | | 65.3 | |
| Dima | 3.86 | 3.86 | 67.92 | 67.92 |
| Babile 1 | 4.7 | | 55.3 | |
| Babile 2 | 3.6 | 3.78 | 69.19 | 53.55 |
| Babile 3 | 3.5 | | 43.7 | |
| Babile 4 | 3.3 | | 46 | |
| Average | 4.4 | | | |

indicating very strong aggregate that can be recycled again more than ones if needed. This also suggests that this aggregate can be used as a new aggregate in HMA mix.

3.5.2 RAP binder Properties

Asphalt content of most old pavements will comprise approximately 3 to 7 percent by weight and 10 to 20 percent by volume of the pavement and is more viscous and lower penetration values as a result of ageing of the old pavement [8]. The report also indicated that the penetration value may vary from 10 to 18 and absolute viscosity from 2000 to 50,000 depending on the time the existing pavement was in service. The need to improve these characteristics is important in the blending process with the virgin materials to get the desired mix characteristics required

**Table 2 Typical breakdown of GHG emissions by work item, $CO_{2e}$ per km: (World Bank, 2010).**

| Emissions ($t\ CO_2$ eq/km) | Expressway | National Road | Provincial Road | Rural Road Gravel | Rural Road DBST |
|---|---|---|---|---|---|
| Earthwork | 161.4 | 15.89 | 12.00 | 2.74 | 2.68 |
| Pavement | 1333.86 | 424.66 | 157.3 | 72.20 | 85.53 |
| Culvert | 238.48 | 51.45 | 16.69 | 11.85 | 11.57 |
| Structures | 1067.99 | 119.39 | 20.57 | 3.03 | 2.95 |
| Road Furniture | 432.4 | 182.42 | 0.00 | 0.00 | 0.00 |
| Total | 3234.12 | 793.81 | 206.56 | 89.82 | 102.74 |

for good performance. Softening aged binder using low viscosity rejuvenator may be possible, however; it is difficult to obtain the two most important characteristics, stability and durability. One of the purposes of rejuvenating agents in recycling of aged pavements should be to improve the ductility and increase the binding ability of the aged asphalt binder.

Like the virgin binder the extracted binder from aged pavement (mixed with rejuvenator) is expected to fulfill the performance requirements such as rheology, adhesion and durability [3]. Therefore, care must be taken in characterizing extracted binder so that requirements are well identified in the preparation of mix designs.

One of the factors that affect characteristics of aged binder is the level of moisture damage to the exiting pavement [15], however, it can be argued that the recycled materials have better performance with respect to moisture damage as the aggregates are already covered by a binder [3]. With respect to the penetration and viscosity of extracted binder, a study showed that these two properties did not show significant difference compared to virgin binder [6]. Blending of binder extracted from RAP and virgin binder requires an understanding of the remaining characteristics of the extracted binder so that a decision is reached as to how much virgin binder to add.

### *3.6 RAP Durability*

Durability of RAP materials is characterized by their resistance to moisture and temperature sensitivity during service life of pavement and therefore, it is defined as the resistance to continuous and damaging effect of water [18]. Durability is also affected by damages on the existing pavement such as stripping. Pavements showing stripping problem should not be recycled as the problem may re-occur in pavements constructed with RAP containing them, while others argue that it can be recycled by using anti-stripping agents [3]. The major types of damages as the measure of durability of recycled pavements are the rutting and cracking. Performance tests conducted on a number of virgin and recycled pavements indicate no statistically significant differences [6]. It also does not behave much differently as long asno difference material components and composition and the construction methods [3].

Apart from minimizing the environmental impact and energy consumption RAP improves durability and results in good stripping resistance of hot mix asphalt containing RAP materials [18]. Durability of recycled asphalt can be improved through stabilization with various stabilizing agents. Most common stabilizer is cement and is used in many recycling projects to increase strength of the mix. Care must be taken as cement causes cracking if applied in large quantity [19]. Examination of the durability of recycled asphalt pavement using cement-less binders and polymers shows that outstanding durability can possibly be achieved [20].

### *3.7 Environmental Impact*

Road is one of the major causes for environmental degradation as it involves deep cuts, removal of vegetation and continuous quarrying of virgin materials. This impact continues throughout the life of the roads as maintenance and rehabilitation requires production and transporting of virgin materials. Environmental impact is the key issues to all relevant stakeholders and minimizing the impact is important to combat the prevailing climate changes. Recycling significantly reduces the GHG emission and other emissions that affect the environment by reducing the Global Warming Potential [21].

Pavements construction generates more $CO_2$ compared to other components of road construction works. In expressway construction the contribution of pavement account for 41% of the total CO2e per km while for the rural gravel road it is 80%, and for rural road but DBST surfacing it is 83%.

*3.8 Benefit/cost of RAP*

RAP materials used in different layers of pavement can be considered cost saving practice as they eliminate the mining, processing and transportation of virgin aggregates. Depending on percentage of RAP material used in the new mix the cost saving varies. As %RAP is increased the saving in cost will increase [22]. Savings can be obtained from transporting and damping of removed asphalt from damaged road pavements on landfill locations. The percentage of RAP materials used in a mix also has impact on the amount of saving obtained. Few studies indicated that as the percent of RAP increased, the saving also increased as shown in Fig. 9. The saving obtained will encourage agencies to use more RAP and reduce land fill associated problems.

*3.9 Application of RAP*

Recycled Asphalt pavement can be used for the purpose of pavement maintenance, rehabilitation, and reconstruction [7]. RAP can be used as granular base or sub-base material in virtually all pavement types, including paved and unpaved roadways, parking areas, bicycle paths, gravel road rehabilitation, shoulders, residential driveways, trench backfill, engineered fill,

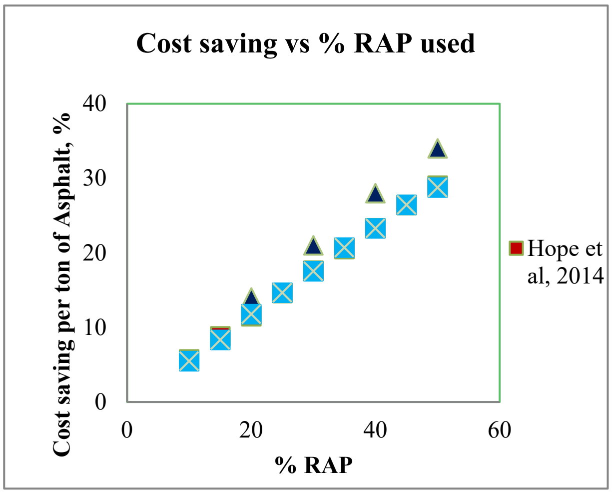



**Fig. 9 Potential cost saving from using RAP.**

pipe bedding, and culvert backfill [8]. As mentioned earlier selected recycling types to be applicable in Ethiopia are CIR, Cold In-plant and FDR and their application is important for fast tracking of backlog on rehabilitation of deteriorating asphalt pavements.

Application of the asphalt pavement recycling methods can also be dictated by the type of defects on the surface of the deteriorated pavement. According to the Asphalt Recycling and Reclamation Association [23], an in-depth condition survey of the pavement shall be conducted to fully understand the types and extents of defects on the pavement. Inadequate information of the condition of the pavement may lead to improper selection and use of recycling methods.

## 4. Policy Framework Development

During the initial stages of the RSDP, A1 trunk road has been recycled and used as base course. In the later stage 65 km segment on Trunk Road A3 has been rehabilitated using Foamed bitumen technology. These are the recycling efforts that can be mentioned in the Ethiopian Road sector in terms of the existing practice regarding recycling.

So far there is no guideline or policy framework for the implementation of asphalt pavement recycling. One of the aims in this study is to develop policy framework that is required for the successful implementation of asphalt pavement recycling in Ethiopia. Recycling is

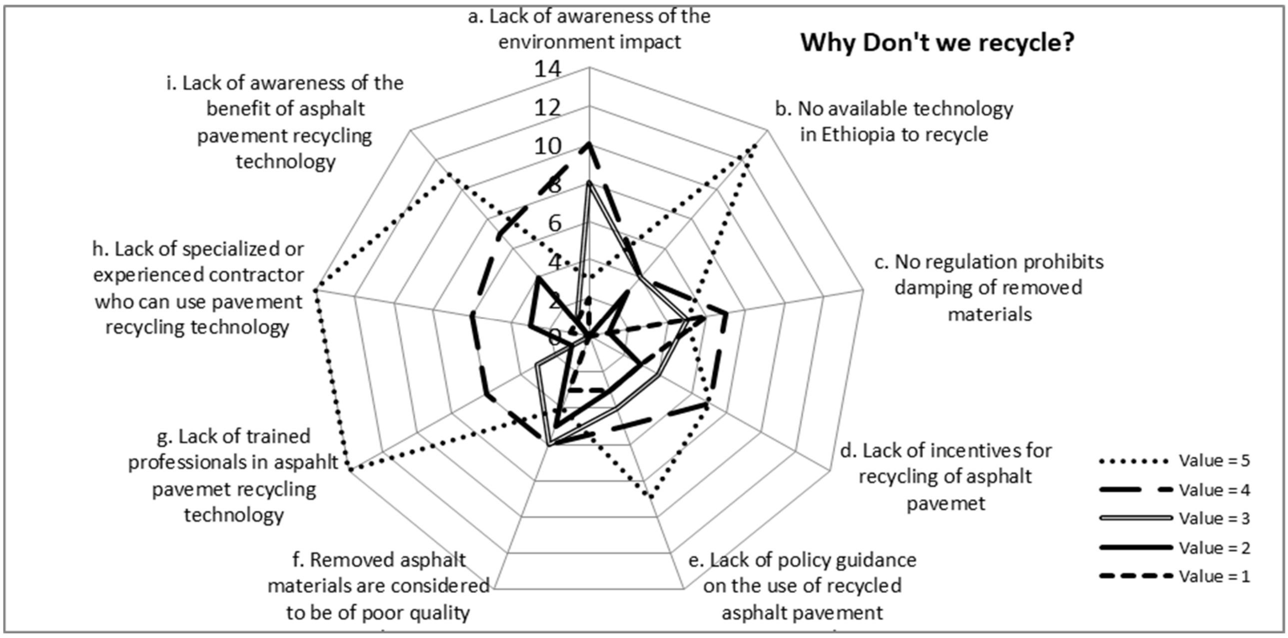


**Fig. 10 Questionnaire response regarding factors of not recycling.**

not well practiced due to various reasons while assumption of natural construction material is abundantly available is overshadowing the fact that natural resources are non-renewable and their uncontrolled use compromise the need of the future generation. The other most important factor is lack of clear policy that guides the use of recycling. Questionnaire was developed and response is analyzed to develop policy for Asphalt pavement recycling.

Accordingly, 92% of respondents have agreed that a policy framework is required. It is generally agreed by respondents that asphalt pavement recycling is attractive to developing countries but can be applied on major roads only. The response showed that asphalt pavement recycling can improve the environment and contribute to good road asset management. Why recycling is not implemented in a wider scale in Ethiopia may have many reasons. The questionnaire response showed that the factors affecting the implementation in the graph below.

Lack of policy is not taken as a serious hindrance factor, rather lack of specialized or experienced contractor and professionals who can implement the recycling, and unavailability of required technology are responsible. It is also believed that there should be incentive mechanism for contractors to recycle. Types or forms of incentives may vary and which incentive is most interesting to them in the Ethiopian context is assessed. Accordingly, loan facilitation for equipment purchase is more interesting while hard currency provision, tax exemption on equipment importation and development of standards and specification are considered as incentives.

Desired asphalt to be recycled is 50% according to 38% of respondents. 21% suggested 100% recycling, 17% of respondents suggested 10% There is a concern that 100% recycling may not be achievable at the beginning due to lack of industry experience and better to start with lower percentage of recycling.

In conclusion the result from questionnaire analysis shows that asphalt pavement recycling needs to be supported by policy framework and incentives shall be put in place to make recycling attractive.

## 5. Suggested Policy Statement

It can be understood from literatures that asphalt can be recycled 100% and this can be done repeatedly. By demolishing and wasting this precious material we are losing a very good quality aggregate, time and money while we are significantly degrading our environment. Therefore, it is time to encourage public and private contractors to recycle asphalt pavements through incentives and penalty schemes. The following are suggested policy statements formulated based responses from the questionnaire and systematic review.

1. Asphalt pavement recycling will benefit the industry and our environment through cost saving, minimized use of virgin materials, reduced GHG emission, and cutting energy demand;
2. On road rehabilitation projects a minimum of 50% of existing asphalt pavement material shall go back to the road either in the lower layers or on surfacing as design suggests, while the rest is taken to central processing location;
3. Asphalt pavement recycling shall be a priority option in the design of rehabilitation projects;
4. Government through implementing organization provides training and awareness creation on asphalt pavement recycling;
5. Government shall facilitate for and encourage investors to invest in asphalt pavement recycling;
6. Penalty shall be applied on contractors or public bodies for damping removed asphalt pavement materials as landfills;
7. Government shall provide support for importation of recycling machines and accessories through hard currency facilitation and tax exemption;
8. Federal Roads Authority shall lead asphalt recycling initiatives;
9. Research and trials are encouraged to maximize recycling and increase innovation for implementation of asphalt pavement recycling;
10. Construction and rehabilitation projects shall accommodate trial sections whenever needed by the implementing organization.

## 6. Conclusion and Recommendations

Asphalt Pavement Recycling will support the effort of restoring the deteriorating asphalt road network in Ethiopia. The outcome of this research has indicated there is cost saving, environmental protection and minimized quarrying of virgin material by recycling an already exiting good quality material on the road. Binder will lose its property due to ageing and becomes brittle and less viscous and thus needs rejuvenating if used in asphalt mix. Aggregates on the hand are better performing except a change in gradation during reclaiming process. Test results show that strength parameters did not change suggesting that reclaimed aggregates can be used in HMA mix equally as virgin material. It can be concluded that RAP is proved to be durable, economical and environment friendly precious material to be handled with care and be reused over and over again. The following are conclusions drawn from this research.

1. Cold In-place, Full Depth Reclamation and Cold In-plant recycling are most desirable recycling method that can be implemented in Ethiopia;
2. The cost saving from recycling can vary from 20% to 80% depending on the project size and type;
3. Asphalt pavement can be 100% recycled and this can be done repeatedly as many times when the pavement deteriorates;
4. Aggregates in RAP retains its original quality so that it can be used equally as virgin aggregate;
5. Policy framework is required to facilitate a smooth implementation of selected recycling techniques/methods.

It is highly recommended to start implementing the three selected recycling methods, Cold In-place, Cold In-plant and FDR so that the precious material siting out on the road can be wasted no more in Ethiopia.

## Acknowledgment

The Ethiopian Roads Authority who has facilitated this research is highly acknowledged. I would like to sincerely thank Dr. Mahububal Bari, who initiated and supported this research program is also acknowledged. The central laboratory team leader and his staff at the

Ethiopian Roads Research Center are highly acknowledged for their support and testing samples at their laboratory. All those participated in this research directly or indirectly are highly appreciated.

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