JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIROMENTAL ENGGINEERING

HIGHWAY ENGINEERING STREAM

INVESTIGATION ON THE PARTIAL USE OF DEMOLISHED CONCRETE WASTE AS COARSEAGGREGATE IN HOT MIX ASPHALT

A Thesis submitted to the School of Graduate studies of Jimma University in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering (Highway Engineering)

By:

Kinfe Gebrgeorges

February, 2021 G.C

Jimma, Ethiopia

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Approved by Board of Examiners

______________________	______________	____/____/____
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Ass.Prof.Getachew Kebede(Ph.D.)	______________	____/____/____
Main Advisor	Signature	Date
Eng. Girma Fikre (MSc)	______________	____/____/____
Co-Advisor	Signature	Date

Declaration

I, the undersigned, declare that this thesis entitled **"Investigation on the partial use of demolished concrete waste as coarse aggregate in hot mix asphalt"** is my original work, and has not been presented by any other person for any award of a degree in this or other University, and all sources of materials used for this thesis have been duly acknowledged.

Candidate

Kinfe Gebrgeorges:

Signature: _______________

As Master's research advisors, we here by certify that we have read and evaluated this MSc research prepared under our guidance by **Kinfe Gebregeorges** entitled **"Investigation on the partial use of demolished concrete waste as coarse aggregate in hot mix asphalt".** We recommend that it can be submitted as fulfilling the MSc thesis requirements.

Ass .Prof .Getachew Kebede (Ph.D.)	________________	_____/_____/_____
Main Advisor	Signature	Date
Eng. Girma Fikre (MSc)	________________	_____/_____/_____
Co-Advisor	Signature	Date

Acknowledgment

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Abstract

Disposing of demolished concrete wastes has substantial adverse effects for the construction industry and as a whole for the natural environment. One of that is excess loading on landfills which are not sufficient for other non-recyclable materials and the other is not backing up of the natural aggregate which depletes through time due to the flourishing construction activities in the country. Hence the aim of this work is to investigate the effect of using demolished concrete waste as a coarse aggregate in hot mix asphalt.

The research studied that the physical and geotechnical properties of demolished concrete waste aggregate through intensive laboratory tests and laboratory tests were conducted for hot mix asphalt prepared and tested by Marshall Mix design method with incorporation of demolished concrete waste aggregate in proportions of (0%, 25%, 50% & 75%).The volumetric properties of paving mixture investigated and optimum bitumen contents were determined for the different percent compositions of demolished concrete waste aggregate. Marshal flow & stability tests were conducted to know the performance of paving mixture and performance test regarding moisture induced damage was conducted in laboratory since the absorption of demolished concrete waste aggregate was greater than that of natural crushed aggregate.

The test results shown that the physical property of demolished concrete waste aggregate has lower specific gravity and higher water absorption than natural crushed aggregate and it shows good resistance to Los Angeles Abrasion and static crushing load whereas the aggregate crushing value is out of ERA specification. The volumetric properties (Air void, voids in mineral aggregate), stability & bitumen contents increase as the percentage composition of demolished concrete waste aggregate increase whereas 75% demolished concrete waste aggregate replacement does not fulfill the ERA and MS-2 criteria of flow, stability and voids filled with asphalt.

Hot mix asphalt incorporated with 25% & 50% demolished concrete waste aggregate shows good performance against moisture induced damage. The test results have shown that 25% up to 50% demolished concrete waste replacement can be utilized as coarse aggregate in hot mix asphalt.

Key Words; *Demolished concrete waste aggregate, natural crushed aggregate, hot mix asphalt and bitumen.*

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List of Acronyms

AASHTO	American Association of State Highways and Transportation Officials
ASTM	American Society for Testing and Materials
DCWA	Demolished Concrete Waste Aggregate
DBC	Design Bitumen Content
ERA	Ethiopian Road Authority
FHWA	Federal Highways Agency
GP- GS	Poorly Graded Gravel Sand mix
ITS	Indirect Tensile Strength
HMA	Hot Mix Asphalt
JMF	Job Mix Formula
JPCP	Jointed Plain Concrete Pavement
MDD	Maximum Dry Density
MS	Manual Series
MTD	Maximum Theoretical Density
NA	Natural Aggregate
NCA	Natural Crushed Aggregate
OAC	Optimum Asphalt Content
OBC	Optimum Bitumen Content
PCC	Portland Cement Concrete
RCA	Recycled Concrete Aggregate
CCA	Crushed Concrete Aggregate
TSR	Tensile Strength Ratio
VFA	Void Filled with Asphalt
VMA	Void in Mineral Aggregate
VTM	Void in Total Mix
LAA	Los angles Abrasion
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
DCW	Demolished Concrete Waste

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Chapter - 1

Introduction

1.1. Back ground

The growing population and the demand for improved and comfortable life style derive rapid expansion in urbanization which in turn requires immense infrastructures. The infrastructures desired by human being inquire eventual sophistication in design and construction. To this effect, construction materials are the entities which are gained naturally with direct exploitation. Gradually the irreversible natural resources are degraded on the contrary of the enhanced demand. Finding solution for this disastrous environmental depletion and for the unsatisfied demand requires comprehensive and integrated effort.

Recycling of materials is considered as one of the solution for the mentioned problems. Since the material demand in construction is highly accelerated, recycling of demolition concrete wastes for multi-purpose importance is focused in this work. Recycling of demolition concrete wastes are alarmed when the environmental impact noticed and when scarcity is faced. Recycling of Portland cement started in Europe after World War II. With time and through necessity, recycled aggregates have become increasingly acceptable as road construction materials. Many countries also start to accept, regulate, specify and implement utilization of recycled concrete in their corresponding manuals. In recent years the use of Recycled Materials has been considered in road construction with great interest in many advanced industrialized and newly industrialized countries. Use of recycled material in road construction applications is beneficial because it reduces the environmental impact and economic cost of quarrying operations, processing, conservation of landfills and transport. (Khope, R.A. and Mohod, M.V., 2015.).

Our country, Ethiopia shows encouraging growth and attempt to transform into industrialized economic system. This transformation and economic development derives great demand for construction of infrastructures followed by the increased demand of construction materials. This growth also led to replacement of old infrastructures by the new construction. Due to this effect demolition wastes are highly increasing through time because of: right-of-way in urban and suburbs and demolition of curbing structures, new urban planning especially in the capital city and private economic growth to replace old building with modern and high rising ones(Yehualaw,M.D.andWoldesenbet,A.K.,2016.)

Investigation on the use of demolished concrete waste as a coarse aggregate in hot mix asphalt surface course towards the glitches stated above and to gain the merits of recycling demolition concrete wastes. Researches should have to address this area to investigate the possible utilization of demolished concrete wastes for conserving landfills which is very limited in the country, to keep the natural virgin aggregate, to save energy and money. The research is the one which intends to add up some value to the recycling world by evaluating the properties of demolished concrete waste aggregate for utilization in hot mix asphalt surface course in flexible pavement road. To date only a small number of investigations have dealt with the use of recycled concrete aggregate in hot mix asphalt(HMA).The performance of HMA made with coarse RCA is related to their heavily crushed face, which contributes to the internal friction for permanent deformation resistance. From this point of view, HMA made with coarse RCA showed a better performance in terms of permanent deformation and stiffness than HMA elaborated with only natural aggregates (NA).(Shen,D.H.andDu,J.C.,2004.).

The mechanical and volumetric properties of mixtures containing RCA achieved a slightly better performance than conventional mixtures. They considered it feasible to use waste concrete as partial aggregate substitution in HMA. However, no test of any kind was carried out to evaluate its sensitivity to water action. (Wong, Y.D., Sun, D.D. and Lai, D., 2007.). The mechanical and volumetric properties of HMA made with different % of DCWA. When the % of DCW was increased from 0% to 75%, the stiffness decreased and the rutting failure potential increased. Even so, according to these authors, demolished concrete waste is capable of serving as a useful replacement in HMA roadways where traffic loads are minimal. They were able to design HMA mixes which satisfactorily resist moisture and water-related damage (stripping). Nevertheless, they revealed that as the % of RCA increased the degree of moisture susceptibility of the HMA mixes also increased (Mills-Beale, J. and You, Z., 2010).

Ethiopia is also one of the fastest growing countries and this can be witnessed by observable enhancement of construction activities in the country and demolitions for the replacement of old buildings, rehabilitation of land uses and rehabilitation of urban streets. The flourishing construction activities are demanding more raw materials and the demolitions also cost more for land filling.

This unbalanced phenomenon can be regulated by considering recycling of demolition concrete wastes aggregate for reutilizing in different applications. Even though utilizing demolition wastes as road building materials is customary to developed countries there is no trials to use in Ethiopia except including the specification to use recycled asphalt pavement (RAP) in the national road authority manual. Towards the information stated above and to gain the merits of recycling demolition concrete wastes researches should have to address this area to investigate the possible utilization of CDW's for conserving landfills which is very limited in the country, to realm the natural aggregate, to save energy and money.

1.2. Statement of the problem

Disposing of demolition concrete wastes has substantial adverse effects for the construction industry and as a whole for the natural environment. One of that is excess loading on landfills which are not sufficient for other non-recyclable materials. The other is not backing up of the natural aggregate which is depleted through time due to the flourishing construction activities in the country and thirdly losing economic advantage from saving of disposal costs at landfills and transportation cost for rarely and far located landfills in the urban areas. Fuel and energy consumption at time of quarrying is also additional cost.

The potential sustainability benefits associated with the use of demolished concrete waste aggregates are many, including the preservation of natural resources, the reduced environmental impacts associated with both the production of new materials and the disposal of the recycled concrete waste materials (often expressed in terms of greenhouse gas emissions and energy consumption), and cost savings achieved by incorporating the recycled material (Dam & Dufalla, 2016).

The aim of using demolished concrete waste aggregate for hot mix asphalt is, one to reduces environmental deterioration resulting from blasting of more quarry areas to produce the required amount of virgin aggregate by providing demolished concrete waste as alternative aggregate material which is easily available in the construction sites in which replacing old buildings with new one or right of way obstruction removal in road construction. Secondly, this state of art collects information that could be helpful when planning new investigations and generalizing the sustainable use of demolished concrete waste aggregate (DCWA) in hot mix asphalt.

To achieve all of these objectives, first, a description of demolished concrete waste aggregate is provided for hot mix asphalt production with partial replacement of natural aggregate. Second, the paper summarizes the main properties of hot mix asphalt containing demolished concrete waste aggregate (DCWA). Lastly, field experiences and specifications are analyzed then the main conclusions were presented.

1.3. Research question

The researcher formulates the following research questions to conduct the study:-

i. What are the properties of demolished concrete waste (DCW) to be used as coarse aggregate in hot mix asphalt?
ii. What are the effects of using demolished concrete waste aggregate (DCWA) on the properties of hot mix asphalt?
iii. What are the optimum percentage replacements of demolished concrete waste as coarse aggregate (DCWA) in hot mix asphalt?

1.4. Objectives

1.4.1. General objective of the study

The general objective of this study is to investigate the properties of demolished concrete waste use it as coarse aggregate in hot mix asphalt of flexible pavement road surface.

1.4.2. Specific objective

i. To determine the properties of demolished concrete waste to use it as coarse aggregate in hot mix asphalt.
ii. To determine the effect of using demolished concrete waste as aggregate on the properties in hot mix asphalt.
iii. To determine the optimum percentage replacement of demolished concrete waste aggregate in hot mix asphalt.

1.5. Significance of the study

Utilizing demolished concrete waste as aggregate material in road construction gives relief for the natural environment with deteriorations resulting from blasting of more quarry areas to produce the required amount of natural crushed aggregate and it keeps the virgin aggregates. Demolished concrete waste gives additional sources of aggregate for hot mix asphalt production. The study also determines the performance of hot mix asphalt that is to be done with the replacement of conventional material (natural crushed aggregate) with demolished concrete waste aggregate.

The other possibility of to be used as coarse aggregate material in hot mix asphalt of a Marshall Mix design and this can imply demolished concrete waste as an alternative aggregate material from its sources which directly relate to the concept of income generation and job opportunity creation for the peoples.

1.6. Scope and limitation

The study explores the literatures about utilization of demolished concrete waste as coarse aggregate material in hot mix asphalt and conduct laboratory tests to investigate the physical and geotechnical properties of demolished concrete waste aggregate and conduct Marshall Mix design for dense graded hot mix asphalt by incorporating demolished concrete waste aggregate in different proportions with natural crushed aggregate to assess the volumetric and performance properties of the hot mix asphalt paving mixture. Marshall (Flow and stability) test and moisture damaged resistance tests was conducted and the properties are evaluated according to ERA standard specifications for deferent applications. The performances of recycled concrete aggregates on site is not evaluated since there is no pavement constructed with recycled concrete aggregate

CHAPTER - 2

LITERATURE REVIEW

2.1. Introduction

Construction and demolition wastes (CDW) are produced during all stages in the life of a building (Kazal, S.S.2015).Construction and demolition (C&D) debris is the waste material that results from the construction, renovation, or demolition of any structure, including buildings, roads, and bridges. Typical waste components include Portland cement concrete, asphalt concrete, wood, drywall, asphalt shingles, metal, cardboard, plastic, and soil (GanironJr, T.U., 2015.). Major prominent sources of construction & demolition wastes are: waste arising from the total or partial demolition of buildings and/or civil infrastructure, waste arising from the construction of buildings and/or civil infrastructure, soil, rocks and vegetation arising from land leveling, civil works and/or general foundations & road planning and associated materials arising from road maintenance activities. Among these waste materials, not all are advantageous and concern of recycling. Whereas cross contamination and general mixing of materials is frequently observed on construction and demolition sites. This is of greatest concern if the mixing involves hazardous materials. This applies to materials such as asbestos and to certain heavy metals (such as lead), solvents and adhesives (Symonds Group Ltd, ARGUS, COWI, PRC Bouwcentrum, 1999).

It is the major attention area to identify the composition of these waste materials in order to consider in recycling and re-using rather than to pull off and land filled without any advantages and for adverse effects on environmental and economic aspects. Not only knowing the quantitative composition of the wastes led to decision for recycling but also their particular nature of the wastes in advance. To this regard wastes are classified broadly as recyclable and non-degradable (inert) based on the recycling concept. This broad classification in turn disintegrated by different category. According to report to DGXI, European Commission this classification of CDW is as follows: i) concrete, bricks, tiles, ceramics, and gypsum based materials; ii) wood; iii) glass; iv) plastic; v) asphalt, tar and tarred products; vi) metals (including their alloys); vii) soil and dredged spoil; viii) insulation materials; ix) mixed construction and demolition waste (Symonds Group Ltd, ARGUS, COWI, PRC Bouwcentrum,1999).

Here in this research the main waste concerned among those types of wastes is demolished concrete rubble from different sources for reutilization as aggregate from the demolished concrete for road pavement construction.

2.2. Abundance of demolished concrete waste (DCW)

As many literatures revealed that, rapid economic growth of the globe increased demolition wastes significantly increase. The reasons for such increments are so many factors. For instance may be due to the objective of replacement of old structures with the new one, due to the right of way for expansion of new industries, roads and other infrastructures, due to new policy of urbanizations and so on (Sahay,A.,&Saini,G.,2015). After world war-II the amount of demolition wastes increases abruptly due to the devastating effect of the war. Yet war is not the only cause for increment on the quantity of demolished waste. Development of the country or institutional change from agrarian to industrialization makes the abundances in DCW. Accordingly developed country now has generating multi million metric tons of demolition wastes annually.

For instance the Italian production of inert demolition materials amounted to approx. 35 million tons. (M.Cupo-Paganoetal., 1994) whereas statistics In Norway indicates that the approximate amount of demolition waste generated yearly is 1.5 million tons. (Petkovic,Engelsen,Håøya,&Breedveld.,204;Aurstad,Aksnes,Dahlhaug,Berntse,&Uthus,2005).In the USA, over 130 million tons of Construction and Demolition (C&D) waste is produced each year. In Australia, more than 14 million tons of C&D waste was generated in 2004/2005(Cameron, D.A., & Gabr, A.2010). India at 2009 was generating construction and demolition (C &D) waste to the tune of 23.75 million tons annually (Yadav, S.R. and Pathak, S.R., 2009,).In Netherland total amount of 14 Million ton produced every year (Hendriks, 2016; Hendriks & Janssen, 2001). From the mentioned figures it can be observed that economically advanced countries generates enormous amount of demolition wastes. Newly industrialized countries like Thailand, China, India, Malaysia, Sri-Lanka and Vietnam generates substantial amount DWs and increasing rapidly through time (Manowong,E. and Brockmann,C.,2015.).

Here in Ethiopia also substantial efforts are done to be industrializing country through the GTP (Growth & Transformation Plan). To this effect tremendous construction and demolition wastes are observed at present time and the abundance can be projected for the future.

Even though there is no figurative fact sheets on the annual production of demolition concrete wastes one can be confidently witness as the quantity of construction and demolition wastes are increasing through time due to different policies of urbanization.

2.3. Utilization of coarse aggregate from DCW's

Global production of construction and demolition waste has significantly increased over the last few decades, causing environmental problems due to its uncontrolled disposal. The use of recycled materials has been on the rise during the same period, primarily for the purpose of sustainable development and protecting the environment. The main material included in DCW's is the cement concrete from which, by application of appropriate recycling technologies, recycled aggregates result; they can successfully substitute crushed/quarry natural aggregates to the construction of rigid pavements, fresh concrete, and layers of flexible pavements (Kazal,S.S.2015).

The most widely used recycled materials are recycled asphalt pavement (RAP) and recycled concrete aggregate (RCA). The aggregates in RAP are coated with asphalt cement that reduces the water absorption qualities of the material. In contrast, the aggregates in RCA are coated with a cementations paste that increases the water absorption qualities of the material. Thus the recycled aggregates can be utilized for reconstruction of building by casting as fresh concrete or as rigid pavement and/or as different layers of flexible pavements

2.4. Recycled concrete aggregate (RCA)

A simple visual inspection helps to determine the differences between RCA and natural aggregates (NCA). A common RCA particle consists primarily of an aggregate partially covered by a mortar layer. This attached mortar is more porous and less dense than the original natural aggregate (Paranavithana,S.andMohajerani,A.,2006.&Pérez,I.,Pasandín, A.R. and Medina, L., 2012.) and has relatively weak bonding with the original natural aggregate (Tam, V.W., Tam, C.M. and Le, K.N.,2007.), which negatively affects the RCA properties. Moreover, the attached mortar has a variable content or thickness, age, composition, porosity and texture. Nevertheless, In this regard, most authors only highlight the influence of the attached mortar content on the properties of the RCA without taking into account all of the other properties previously discussed. Only a few studies (Lee, C.H., Du, J.C. and Shen, D.H., 2012.).

Evaluation of pre coated recycled concrete aggregate for hot mix asphalt. *Construction and Building Materials*, indicate that small cracks appear during the crushing process that degrade the properties of RCA are generally lower quality than natural aggregates (Lee, C.H., Du, J.C.and Shen, D.H.,2012.) and will affect the performance of hot-mix asphalt.

2.4.1. RCA for flexible pavement road construction

From the beginning of the concept of recycling of demolition concrete waste aggregates from concrete rubble is used for road construction in flexible pavement either as fill material or as layers above fill and in rigid pavement as concrete source. Here below some literatures are reviewed in this regards. Flexible pavement contains different layers with lower quality at the bottom and better quality at the top. Recycled concrete aggregate is used for different layer construction of flexible pavement. It started from earth fill without requirement of any treatment to the surface layer with different treatments and extensive research works. Literatures collected from different sources conduct various experiments to utilize recycled concrete aggregate as aggregate material in hot mix asphalt surface course.

2.4.2. Recycled concrete aggregate in HMA

Recent researches focus on the advanced utilization of recycled concrete aggregate to surface courses and/ or bitumen bounded road bases. This gives more benefit since the aggregate required for this purpose had more quality than sub bases and other layers in pavement constructions. Here below some literatures are presented regarding of application of recycled concrete aggregate as bituminous pavement layers. As stated by the research of (M.Cupo-Paganoetal., 2000).

Experimental studies that make it possible to consider using RCA for the manufacture of bitumen-treated base course with good mechanical strength characteristics were conducted. The results were satisfactory and allowed to state that a huge fraction of traditional aggregate may be replaced with recycled material. According to their opinion the examined material were satisfactory and allowed to point out the considerable savings in demolition waste exploitation, with greater advantages from the energy and environmental point of view (M.Cupo-Paganoetal.,2000).With the scope of evaluating static and dynamic mechanical properties of mixtures containing Different percentages (0%, 15%, 30% & 50%) of demolition concrete waste materials, paper et al. concluded that C&D materials can conveniently be used in asphalt concrete for base layers (up to maximum 30%) without penalizing the mechanical performance of the mixture

(Paper et al.,2014). In another performance and other properties testing research work it is revealed that aggregate properties, volumetric properties of bitumen specimens containing RCA were relatively low compared to fresh aggregate properties, but the Marshall Stability value was higher for RCA compared to fresh aggregates with conventional bitumen and modified bitumen, the rutting deformation was higher for fresh aggregates compared to RCA. Some of these measured. Properties were within the acceptable limits, except the water absorption for 100% RCA, sample used in this study (Heeralal, M., Kumar,P.R., Rao,Y.V. and Kalyan,V.T.S.,).

Another experimental studies conducted to use RCA in bituminous mixture exposed the strength variation of bituminous concrete surface course in which recycled aggregates are used in partial or full replacement of natural aggregates. Marshall‘s method is used to study the strength variations in bituminous concrete surface course with replacement of natural aggregates with recycled aggregates. It was found that replacement of natural aggregates by recycled aggregates up to 20% is possible in bituminous concrete surface course without significant impact on the strength characteristics. However there is an increase in the binder content for which there is a need to study the economic value of the replacement (Gurukanth, S., D’souza, D.N., Babu, A., Vivek, A.K.andNaik, S.M., 2012.). similarly the study accompanied with the aim of studying recycled construction and demolition waste aggregates to create hot asphalt mixtures for urban paved roads, concluded the use of construction and demolition waste aggregates in percentages of up to 20% for paving urban roads is feasible after conducting tests with four different proportion of replacement 10%-40% (Ossa, A., García,J.L.and Botero,E.,2016.). Studies on moisture damage of recycled concrete aggregate done and the retained Marshall stability and tensile strength ratio are calculated by using two types of anti-stripping additives (hydrated lime and Portland cement). The results showed that both lime and cement could increase Marshall Stability, resilient modulus, tensile strength and resistance to moisture damage of mixtures especially at higher condition periods. Use of hydrated lime had better results than Portland cement (Behiry, A.E.A.E.M., 2013.).

Another article evaluates the possibility of designing hot asphalt mix road pavements using Construction and demolition waste as coarse recycled aggregates with the percentages of recycled aggregates used in the mixtures: 0%, 20%, 40% and 60%. Cement and lime were used as fillers. The mixtures made with coarse recycled aggregates complied with the Marshall technical specifications for low volume roads. The mixtures also showed good resistance to permanent deformation evaluated by means of wheel tracking tests. Never the less, the mixtures made with RA may have insufficient durability due to their high susceptibility to water action which was evaluated using stripping tests (Pérez, I., Pasandín, A.R. and Medina, L., 2012.).

2.4.3. Recycled concrete aggregate as filler material in HMA

Mineral fillers (cement & lime) and fillers from crushing dust are most widely used types in hot mix asphalt even if substantial investigations are conducted to replace those mineral fillers with fly ash, waste lime and cement by pass dust the major aim to add fillers is to maintain the excess air voids in the compacted mixture. Using crushed concrete as filler was investigated and found that crushed concrete aggregate powder can improve the properties of asphalt mixture, such as water sensitivity and fatigue resistance. But it may cause a little decrease of the low-temperature performance (Chen, M., Lin, J. and Wu, S., 2011.).

However it can be summarized that recycled concrete aggregates (RCA) appear to be suitable materials to use in hot-mix asphalt (HMA) for flexible road pavements. However, the poor quality of RCA results in different engineering properties of an HMA using RCA compared to mixtures composed of natural aggregates. Varied laboratory results were obtained, likely because of the heterogeneous nature and origin of the RCA. Nevertheless, a majority of the studies report a high stripping of RCA mixtures. Several treatments help mitigate this problem. Some volumetric properties are discovered and the attached mortar arises many drawbacks not to use with full replacement of natural aggregate. Majorly absorptive property, moisture susceptibility, density, abrasive properties and change of gradation/fragmentation is adversely affect the mixture properties with increasing amount of recycled aggregate.

2.4.4. Merits of recycling /or re-using of DCWA

Researchers are conducted on recycling of aggregates from demolition wastes since there are multifaceted advantages. Among the advantages: environmental sustainability, economic benefits and saving of land fill areas are majorly raised as issue for recycling of aggregates. Several researchers have investigated the reuse of recycled materials for various civil engineering application purposes.

Many barriers exist which prevent maximum utilization, particularly the recognition or acceptance of C&D materials in specifications and the need for research to demonstrate the suitability of recycled materials, as C&D materials have many economic, environmental, and social benefits. Sustainability Victoria (2009) state that the recycling industry is contributing to the environment by reducing greenhouse gas emissions and delivering significant energy, as well as preserving non-renewable virgin resources. In addition to this it creates an employment for the citizens (Schliephake, K., Stevens,G.and Clay,S.,2009.).

2.4.5. Economic merits of using DCWA

When economic merits are referred it meant only quantifiable parameters whereas, other intangible things will be seen in sustainability criteria. (Donalsonetal.2011) performed a sustainability assessment of using RCA versus virgin limestone aggregate (VLA) in base courses from the perspective of environmental, social, and economic aspects. The environmental impact was found to demonstrate a reduced impact in favor of recycled concrete aggregate in process energy and disposal (viz. fuel used to haul concrete to landfill) As per the report of FHWA State of the Practice National Review, the following economic advantages are stated as: Limit haul distance, Reduce disposal costs, Overall project savings, Minimize impacts to existing roads with reduced hauling (―Transportation Application of Recycled Concrete Aggregate FHWA, ‖ 2004). Generally the literatures show that recycling of aggregates from concrete can be used for different applications like for pavement construction: flexible and rigid pavement and as new concrete aggregate with economical manner. Many economic tools are assed in various literatures with different aspect. Energy saving is one of the economic tools. Transportation cost saving is another parameter considered. Savings due to landfill preservation will engender another saving. Hence in addition to recycling of concrete aggregate gives multifaceted economic benefit against land filling to waste.

2.4.6. Environmental sustainability of using DCWA

The potential sustainability benefits associated with the use of these materials are many, including the preservation of natural resources, the reduced environmental impacts associated with both the production of new materials and the disposal of the recycled concrete waste materials(often expressed in terms of greenhouse gas emissions and energy consumption), and cost savings achieved by incorporating the recycled material(Dam & Dufalla,2016).

The use of HMA made with DCA promotes sustainable construction by providing numerous environmental benefits, such as reduced extraction of natural aggregates from quarries, and avoidance of the visual impact of landfills, avoidance of rejection of raw materials. However, there are some disadvantages to the use of DCA in HMA. The cost of removal of impurities (e.g., gypsum) is one disadvantage. There are also environmental disadvantages, such as an increase in bitumen consumption with increasing RCA content and the associated increase in energy consumption. Limiting the RCA content to 30% produces a maximum increase of 0.5% in the bitumen content, which is an acceptable value (Pasandín, A.R. and Pérez, I., 2013.).

Another study done on comparison of quarrying primary aggregates and DCW-derived aggregates done based on noise and dust suggested that for a specific volume of aggregates used in construction (including landscaping), quarrying primary aggregates and land filling the equivalent volume of DCW is less environmentally desirable than recycling the DCW into DCW-derived aggregates (Symonds Group Ltd, ARGUS, COWI, PRC Bouwcentrum, 1999.)..On report of FHWA State of the Practice National Review, environmental advantages of recycled concrete aggregate are mentioned as: Resource Conservation, Conservation of virgin aggregate, Reduce impacts to the landscape, Metal recovery (―Transportation Application of Recycled Concrete Aggregate FHWA, ‖ 2004). In summary it can be seen that recycled concrete aggregate gives infinite relief for environmental sustainability by preservation of the natural balance. This trend shall be promoted by considering such multidirectional merits. Many countries adopt and implement policies and regulations to encourage recycling of these inert materials for usable state for application in transportation infrastructures of specifically sub base, base course and surface courses in addition to PCC pavement application.

2.5. Properties of demolished concrete waste aggregate

A simple visual inspection helps to determine the differences between RCA and natural aggregates. A common RCA particle consists primarily of an aggregate partially covered by a mortar layer. This attached mortar is more porous and less dense than the original natural aggregate (Paranavithana,S.andMohajerani,A.,2006.&Pérez,I.,Pasandín,A.R.and Medina,L.,2012.) and has relatively weak bonding with the original natural aggregate (Tam, V.W., Tam, C.M. and Le, K.N., 2007.), which negatively affects the RCA properties. Moreover, the attached mortar has a variable content or thickness, age, composition, porosity and texture. Nevertheless, In this regard, most authors only highlight the influence of the attached mortar content on the properties of the RCA without taking into account all of the other properties previously discussed. Only a few studies (Lee, C.H., Du, J.C.andShen, D.H., 2012).

Evaluation of pre coated recycled concrete aggregate for hot mix asphalt. *Construction and Building Materials*, indicate that small cracks appear during the crushing process that degrade the properties of RCA are generally lower quality than natural aggregates (Lee Cheng-Hsiao 2012) and will affect the performance of hot-mix asphalt.

Mortar content: CCA has a variable reclaimed mortar content that depends on the original concrete mixture proportions and crushing operations (Hiller et al. 2011). The volume of reclaimed mortar in the CCA also depends significantly on the original aggregate type. CCA processed from concrete originally made with rounded, less porous aggregates has less reclaimed mortar as the concrete tends to fracture at the aggregate-mortar interface during the crushing process. In contrast, more reclaimed mortar is often present if the original concrete was made with porous or crushed aggregates (Applied Pavement Technology, 2011) .Usual mortar content is about 23-44% for 8/16 mm fraction and 33-55% for 4/8 mm fraction. Generally, amount of mortar attached to fine fraction is higher than to coarse fraction (Gutiérrez, A., 2004.). The mechanical properties of the DCA whether used as an unbound base material or bound by cement or asphalt, are highly influenced by the volume of reclaimed mortar (Applied Pavement Technology, 2011).

Specific gravity: CCA particles generally have lower specific gravity values than natural materials, attributed to the reclaimed mortar bound to the CCA particles, which are less dense than most natural aggregates due to its porosity and entrained air structure (Snyder et al. 1994).Specific gravity has been observed to decrease as particle size decreases as reclaimed mortar content increases with reduced particle size (ACPA 2009) (Gutiérrez, A., 2004.).; a.R.R.Pasandín&Pérez,2013; “Evaluation of Recycled Aggregates Test Section Performance FarhadReza,‖2017)

Water Absorption: when mortar content increases, water absorption increases too, especially in the finer fraction 4/8 mm. higher absorption is observed in crushed concrete aggregate due to the porosity of the attached mortar.

This will affect the properties of moisture susceptibility of asphalt mix (Pasandín,A.R.andPérez,I.,2013.;Behiry, A.E.A.E.M., 2013.;Leite et al., 2011;Pasandín, A.R. and Pérez, I., 2015.; “Evaluation of Recycled Aggregates Test Section Performance FarhadReza,‖2017).

Particle Shape and Texture: The relative proportions of original coarse aggregate and mortar in CCA varies with the original concrete mixture design, the properties of the coarse aggregate particles (i.e., the angularity and surface texture, strength and elasticity), the bond between the natural aggregate particles and the mortar, and the type and extent of crushing used in production (ACPA 2009). Nevertheless, both coarse and fine CCA particles are highly angular and have rough surfaces, although the larger particles tend to contain greater proportions of reclaimed natural aggregate, whereas finer particles (those passing the No. 4 sieve) often are mainly crushed mortar (ACPA 2009; "Evaluation of Recycled Aggregates Test Section PerformanceFarhadReza,‖2017; Applied Pavement Technology, 2011).

Abrasion and Soundness: The 100% RCA met the Los Angeles (LA) wear requirement but failed the Washington degradation factor. Whereas the result of test conducted in Spain according to Spanish specification revealed that mixes of 0%, 5%, 10%, 20% and 30% replacement of natural aggregate by RCA, the combined (RCA + natural) LA abrasion coefficient complied with the PG-3 (LA < 25%) for HMA as a base course material in roads in heavy traffic category T00 (A.R.R. Pasandín & Pérez, 2013).Los Angeles abrasion loss percentage of recycled aggregate ranged from 35% to 42%. In Los Angeles abrasion test, all the attached mortar is removed, besides the abrasion suffered by natural aggregate (Gutiérrez, A., 2004.). CCA will commonly fail the sodium sulfate test in ASTM C88 yet pass the magnesium sulfate test; Because of this discrepancy, it is not clear whether ASTM C88 is applicable to CCA materials and consequently many agencies waive these test requirements for CCA (ACPA 2009).

2.6. Properties of hot mix asphalt using DCWA

2.6.1. Asphalt content

The literatures are reviewed by (A.R.Pasandín&,I.Pérez,2015) The majority of studies have stated that HMA using RCA have higher optimum asphalt contents (OAC) than conventional mixtures(WongYD,etal..,2007,PérezI,etal.,2007,PérezI,etal.,2010,PérezI, etal.,2012(Hsiao,Chong&Hsien,2012;ShenD,DuJ,2004;YoonHo,Taeyoung,Tai,Rak,2011; Haifang & Bhusal,2011;Bhusalet al.,2011;Rafi,Qadir, Ali,& Siddiqui,2014) mainly because of the high porosity of the attached mortar (Pasandín, A. R. and Pérez,I.,2013.)

Several typical findings, shown in Fig.2.3, illustrate the relationship between the percentage of RCA and bitumen consumption. As seen in Fig. 2.3, the bitumen content increases with a higher RCA content.

The OAC obtained by the different studies varies greatly. The different materials used (natural aggregates, RCA and fillers) could influence the asphalt consumption. Additionally, the mix design and use of treatments could affect the asphalt content.

However, the national specifications of each country are the primary reason for different OAC for identical percentages of RCA. Fig. 2.1 also indicates that the bitumen consumption is greater when the RCA is added in the fine fraction (Rafi, M.M., Qadir, A., Ali, S. and Siddiqui, S.H., 2014.) because of its greater mortar content (Juan & Gutierrez, 2004) and larger specific surface area. For economic reasons, Bush al et al. proposed that RCA should be added to the coarse fraction to avoid high OAC.

Finally coating the particles present in RCA was difficult during the mixing process, particularly for siliceous particles and quartzite because of the chemical composition of these particles and the bitumen absorbed by the mortar. Additionally, the rough texture of RCA could introduce additional difficulties in the coating process. Thus, in addition to the high OAC content of HMA using RCA, some particles in the RCA are difficult to coat. (Pérez, I., Pasandín, A.R. and Medina, L., 2012.)

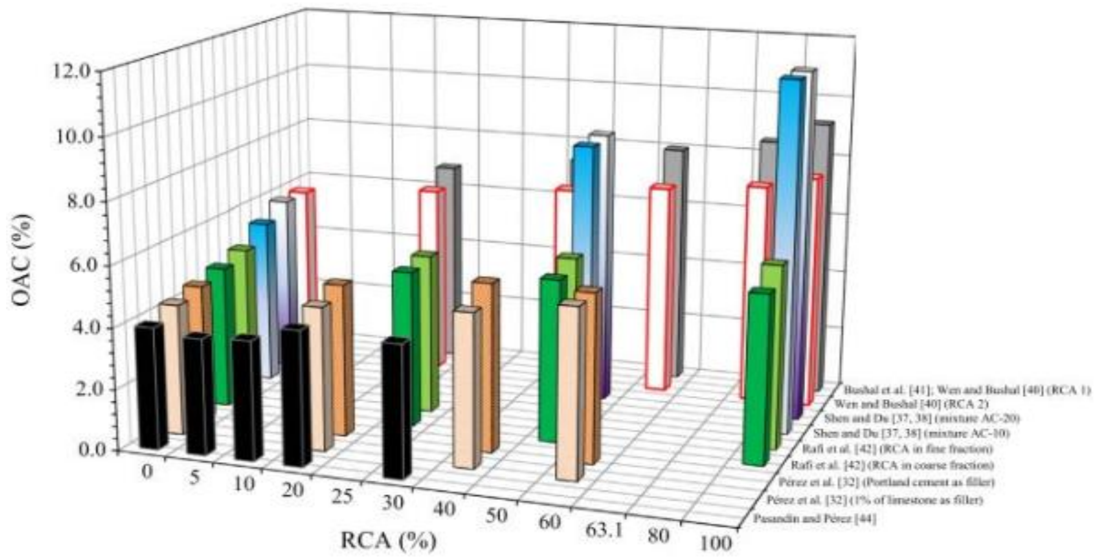


Figure.2.1. Compiled optimum bitumen content of RCA (Pérezetal.2012)

2.6.1. Volumetric Properties

HMA using RCA have higher air-voids contents(VA) than conventional mixtures.(Paranavithana,S.andMohajerani,A.,2006.);the (VA) could exceed 30% for RCA (Cupo-Pagano,M.,D'Andrea,A.,Giavarini,C.andMarro,C.,1994,)Laboratory investigation of demolished concrete waste aggregate as HMA Surface Course Exceed 30% for RCA.

This variation in the air voids content to the high porosity of the attached mortar. (Paranavithana, S. and Mohajerani, A., 2003.).

This high porosity is primarily responsible for the bitumen absorption of the RCA and, thus, the thinner bitumen Film thickness; the thin Film hinders the aggregate interlock after compaction (Pérez, I., Pasandín, A.R.andGallego, J., 2012.) However, this trend was not seen in all studies likely because of the design method used for example some mix design methods indicate that a target air void content or a minimum Film thickness must be reached) so the bitumen content increases as the percentage of RCA increases. The RCA content also affects the voids in the mineral aggregate content (VMA) and the voids Filled with asphalt content (VFA). Several authors indicate that as the percentage of the RCA increases, the VMA and VFA decrease (Bhusal, S., Li, X.andWen, H., 2011.).

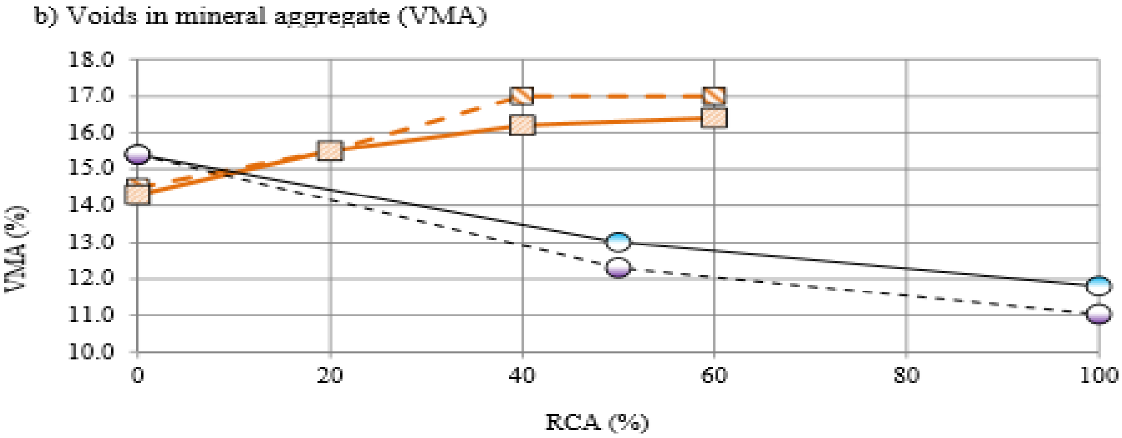


Figure.2.2.Volumetric properties (VMA) of HMA using RCA

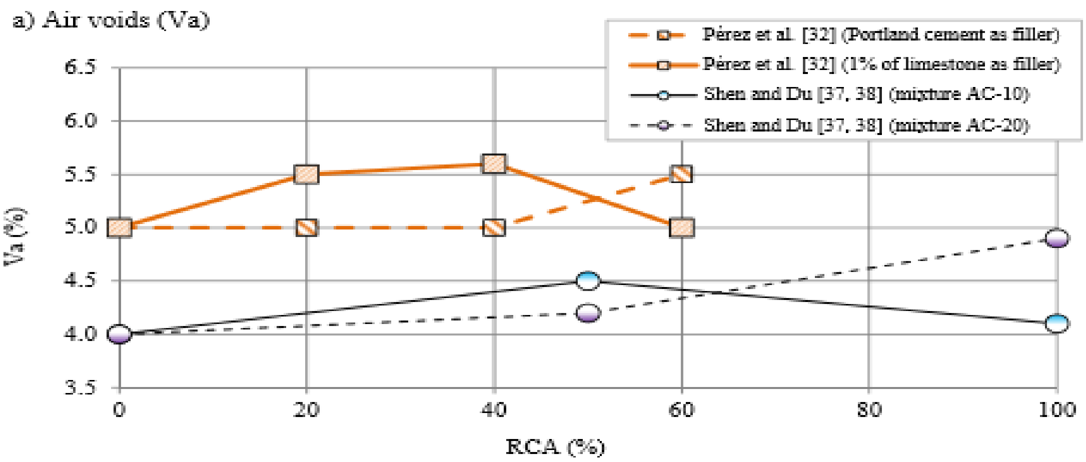


Figure.2.3.Volumetric properties (VA) of HMA using RCA

2.6.2. Marshall Flow and Stability

Marshall Stability of mixtures with RCA is close to that of conventional mixtures (Pasandín, A.R. and Pérez, I., 2014.)This lack of consensus could result from the fraction of RCA used. In this regard (Arabani, M., Moghadas Nejad,F.and Azarhoosh,A.R.,2013.) Indicated that using RCA as fines and filler increased the Marshall stability, whereas (Zhu, J., Wu, S., Zhong, J.and Wang, D., 2012.) indicated that employing RCA in both the coarse and fine fractions resulted in the lowest Marshall stability. The bituminous mixtures using RCA generally meet the national Marshall Stability and flow specifications (Wong, Y.D., Sun, D.D. and Lai, D., 2007, Lee, C.H., Du, J.C. and Shen, D.H., 2012.).Therefore, these mixtures will have a sufficient capacity to withstand traffic loads. However, it is necessary to clarify two issues.

On the one hand, some authors indicate that certain value of natural aggregate replacement by recycle concrete aggregate (RCA) only complies with requirements (CupoPagano, M., D'Andrea, A., Giavarini, C.andMarro, C., 1994,). This limit, which varies between 30% and 50% RCA, depends on the following factors: the nature of the virgin aggregate, the nature and origin of the RCA, the treatment used to improve the RCA properties and the type of mineral filler used. Therefore, with a proper selection of materials used to combine with the RCA (natural aggregate, mineral filler, and bitumen), the requirements for the Marshall stability should be met.

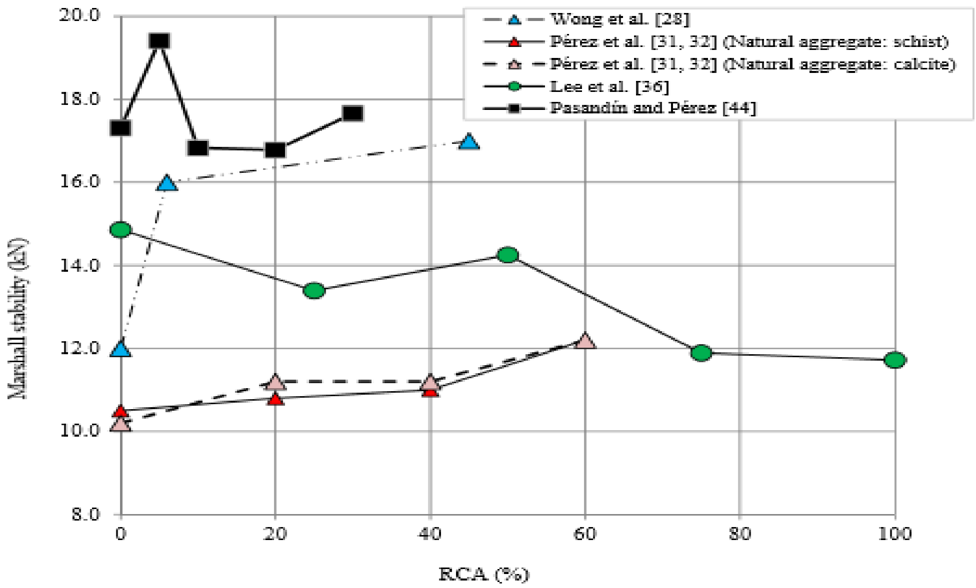


Figure.2.4.Marshall stability of HMA with RCA

2.6.3. Moisture damage resistance

Various investigations indicate that the moisture damage resistance of bituminous mixtures with RCA varies. Thus, moisture damage resistance is a key aspect in the analysis of HMA using RCA and must be carefully studied to guarantee satisfactory durability and performance of such mixtures. The performance depends, among other factors, on the rate of replacement of the natural aggregate by RCA and the nature of both the RCA and natural aggregate. Additionally, the mineral filler has an important role in the success of the mixture.

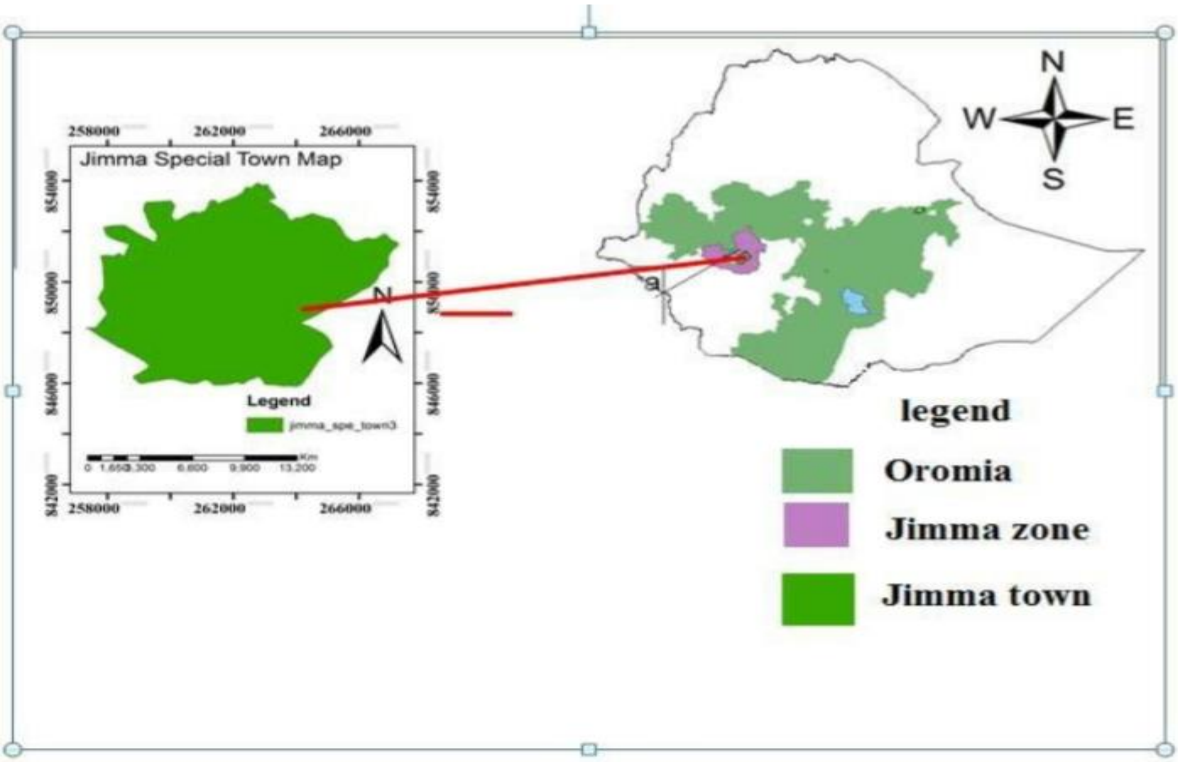
The nature of the RCA is affected by whether the material originates from structures formed exclusively by concrete (e.g., concrete pavements, bridge abutments, etc.) or from buildings, residences, or apartments. Likewise, the composition of the original aggregate (crushed or rounded, mineralogical composition, and texture) also influences the nature of the RCA. Several studies concluded that mixtures using RCA generally meet the national specifications for water resistance. Many of these studies qualify the findings by stating that the resistance to the action of water decreases with an increasing percentage of demolished concrete waste aggregate (DCWA); therefore, for percentages of DCWA over 75%, the specifications are not met. Other studies indicated contrary results in which the water resistance results are far above the minimum required values.

CHAPTER - 3

RESEARCH METHODES AND MATERIALS

3.1. Study area

The study area of the research is Jimma town, Jimma town is found in Oromia regional state south-west of Ethiopia. Its geographical coordinates are between 7°13’- 8°56’N latitude and 35°49’- 38°38’E longitude with an estimated area of 19,506.24 Km^2. Jimma town is found in an area of average altitude, of about (1780 m) above sea level. The city is located approximately a distance of 350 Km away from Addis Ababa, the capital city of Ethiopia.



Source: Google Map.

Fig.3.1. study area Location map

3.2. Materials

Materials that were used in laboratory to perform the goal of the research works are:-

- ❖ Demolished concrete waste aggregate (DCWA).
- ❖ Natural crushed aggregate (NCA).
- ❖ Fillers from demolished concrete waste.
- ❖ Bitumen 60/70 penetration grade as a binding agent.

3.2.1. Demolished concrete waste aggregate (DCWA)

The demolished concrete waste aggregate was collected from Jimma University main campus internal compound in the construction of rigid pavement road and overpass bridge project which is constructed by China Gansu international corporation (CGICOP). In which reinforced concrete retaining wall was demolished. The reason for demolishing of the structure was due to design change of the embankment fill height. Simply sample was collected and the collected sample was broken down in small size to pick easily by hand and the reinforcement was sorted out to separate from the concrete.

This sample was further crushed by asphalt aggregate crusher found at Jimma zone around Natri town owned by ERA Jimma district. The demolished concrete waste aggregate was collected in three sizes ranging from: <4.75mm, [4.75 - 12.5) mm, [12.5-19] mm. The nominal maximum aggregate size (which is one sieve larger than the first sieve to retain more than 10 percent) was 19mm. The maximum aggregate size (one sieve larger than the nominal maximum sieve) was 25mm. This sample was further quartered and prepared for the intended tests as per AASHTO T 2-91 (2000) / ASTM D 75 (2009) specification.

17/07/20, Captured by Kinfe G/georges

Fig.3.2 Demolished concrete waste site and collected demolished concrete.

3.2.2. Natural crushed aggregate (NCA)

The sample of natural crushed aggregate was collected from ERA Jimma district Natri aggregate crusher site. The natural crushed aggregate was collected in three sizes ranging from: <4.75mm, [4.75 - 12.5) mm, [12.5-19] mm. The nominal maximum aggregate size (which is one sieve larger than the first sieve to retain more than 10 percent) was 19mm. The maximum aggregate size (one sieve larger than the nominal maximum sieve) was 25mm. This sample was further quartered and prepared for the intended tests as per AASHTO T 2-91 (2000) / ASTM D 75 (2009) specification.

3.2.3. Filler material (demolished concrete waste dust)

Filler material highly determines the properties of hot mix asphalt. Mineral fillers (cement, lime and crushed stone dust) are most widely used types in hot mix asphalt. For this purpose demolished concrete waste dust used as filler material since demolished concrete waste contains cement and the literature indicated that using demolished concrete waste dust as a filler can improve the properties of asphalt mixture, such as water sensitivity and fatigue resistance.

3.2.4. Bitumen 60/70 penetration grade

The bitumen used for hot mix asphalt test was taken from ERA Jimma district Asendabo stock pile. The bitumen quality test were conducted to verify as the quality is under the specification limit of ERA and other manuals .the bitumen adopted for the research resolution was penetration grade of **60/70.**

3.3. Methods

The methods that were used demolished concrete waste aggregate in Hot Mix Asphalt were as follows: - The collected demolished concrete waste aggregate was further crushed with aggregate crusher for aggregate sieve size and sieved by standard sieve size starting from 25mm to 0.075mm sieve. The optimum percentage rate that used to replace demolished concrete waste aggregate as a coarse aggregate in hot mix asphalt was determined until the optimum potential of demolished concrete waste aggregate can replaced natural crushed aggregate by trial and error method because the study sampling method was purposive. The optimum percentage replacement rates of demolished concrete waste were, 0%, 25%, 50% and 75% of by weight replace with natural crushed aggregate for hot mix asphalt with the optimum filler and optimum bitumen content.

3.3.1. Study design

Different laboratory experiments were conducted to know the quality of aggregates to utilize in hot mix asphalt and volumetric properties of the mix were determined. Hot mix asphalt were prepared and tested with different proportions of demolished concrete waste aggregate and natural crushed aggregate. The summary of materials used and experimental procedures followed to develop the research and the study includes:-

- ❖ Materials (DCWs, NCA, bitumen and filler from DCW).
- ❖ Preparing sample of materials using standard specifications.
- ❖ Preparation of aggregates and bitumen for laboratory tests evaluation.
- ❖ Conduct laboratory tests of each materials used in HMA.
- ❖ Determining the optimum bitumen content and volumetric property of HMA.
- ❖ Find out the optimum blinding ratio of DCWs with natural aggregate (NCA).
- ❖ Data analysis and evaluate the effect of DCWA in hot mix asphalt.

The following portion describes the materials used and the test procedures referenced to ERA, ASTM, BS, Asphalt institute (MS-2 & MS-22), &AASHTO.

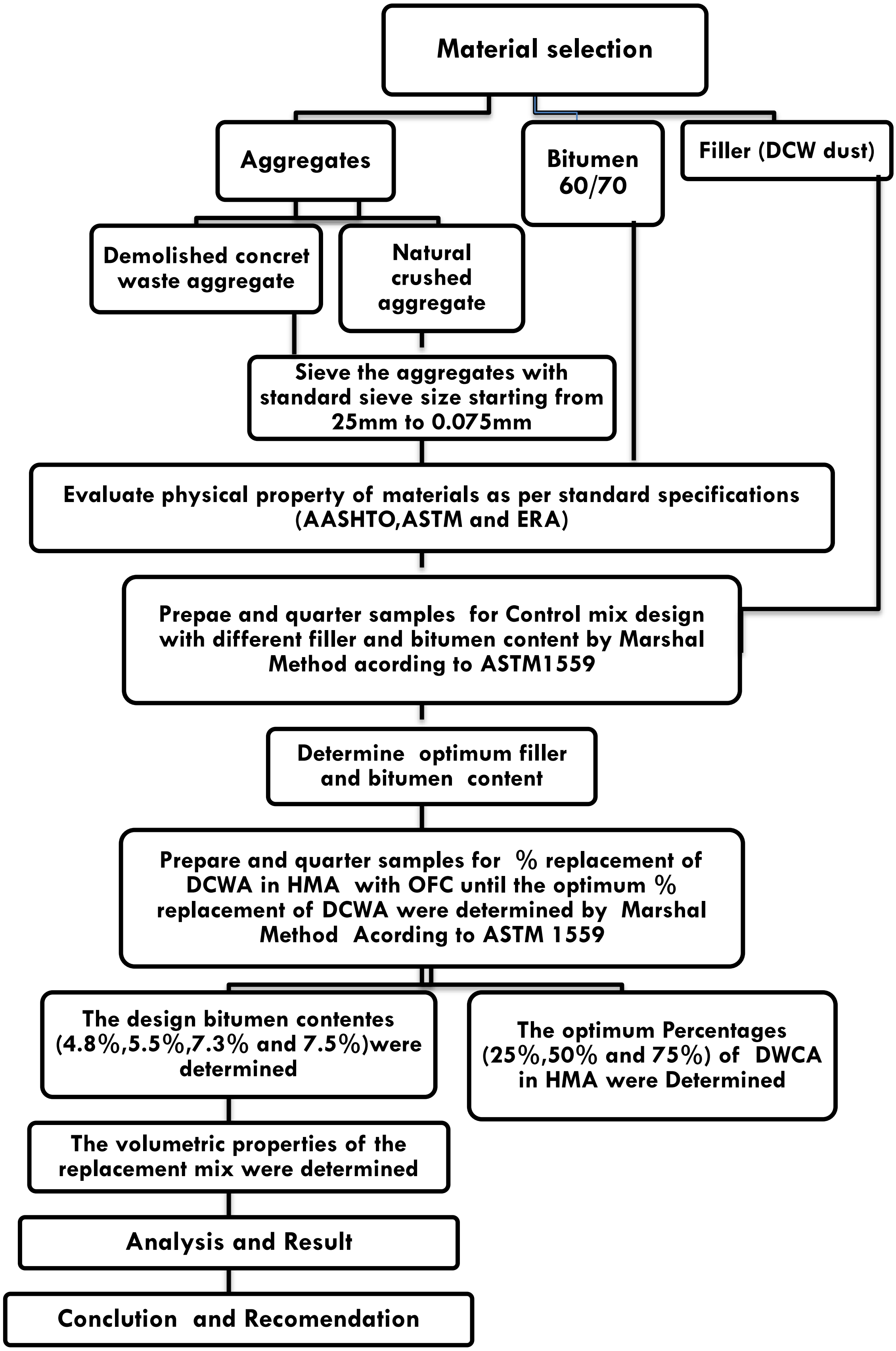


Fig.3.3 Research design chart flow.

3.3.2. Study variables

3.3.2.1. Dependent variable

Dependent variables are related to the general objective of the study due to this the dependent variable of the study is partial replacement of demolished concrete waste (DCW) as a coarse aggregate in hot mix asphalt.

3.3.2.2. Independent variable

Independent variables are: - physical properties of materials (demolished concrete waste aggregates, natural crushed aggregate, filler material and bitumen) and Marshall Properties of hot mix asphalt (Stability, Flow, VIM, VMA, VFA and bulk density)

3.3.2.3. Source of data

For the accomplishment of this research require primary and secondary data. Secondary data was collected from related literatures, existing relevant documents and standards to be analyzing the issue related to the concerned objectives of the study. On the other hand Primary data was the test results of the properties which were determined in the laboratory evaluation.

3.3.2.4. Sampling techniques and sample size

The sample size for the experimental test was determined based on ASTM standards intention to perform laboratory test on the required materials to design hot mix asphalt such as demolished concrete waste, natural crushed aggregate, filler material and bitumen to investigate the effect of demolished concrete waste aggregate in hot mix asphalt by partial replacement of natural crushed aggregate. For each test quartering and weighting was used and the study was performed to compare the design asphalt content (%), stability (KN), Flow value (mm), volumetric properties(VMA%, VTM% and VFA%) through laboratory tests for controlled mix and partial replacement of demolished concrete waste aggregates.

3.3.2.5. Data quality assurance

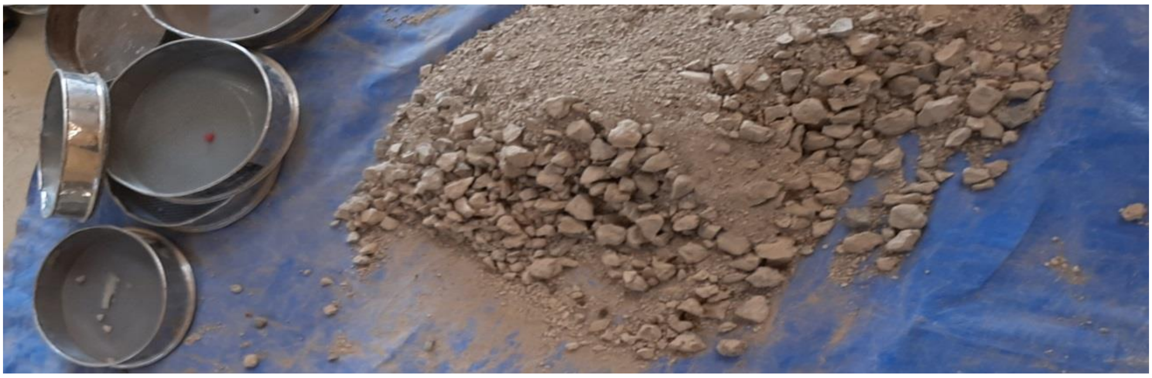
Pre–test of the available instruments were done before the main data collection period begin and the data were collected after gaining an awareness on how to collect relevant data by principal investigator. Samples were collected from appropriate sources and standard formats were used for recording test results to prevent loss of data.

3.4. Physical properties of materials

Prior to testing aggregates, the first procedure was preparing the sample by quartering to get unbiased sample. Accordingly, as per AASHTO T28-96 the demolished concrete waste aggregate sample and the natural crushed aggregate sample was quartered and prepared for the intended test after that sieved by sieve size starting 19mm nominal size to 0.075mm for both demolished concrete waste aggregate and natural crushed aggregate.

3.4.1. Particle size analysis

Since the aggregate from the crusher site was delivered with three sizes, grain size analysis for each sieve size was conducted as per AASHTO T27-99 manual. Blending of these aggregates was done by trial and error to get the desired specification limit grading as per MS-2 and ERA flexible pavement design manual for hot mix asphalt requirements.



27/10/20, Captured by Kinfe G/georges

Fig.3.4 Demolished concrete waste aggregate sample.

27/10/20, Captured by Misgana Ayele *27/10/20, Captured by Misgana Ayele*

Fig.3.5 sieving aggregate and quartering samples (NCA)

03/11/20, Captured by Kinfe G/georges

Fig.3.6 Sieved aggregate (DCWA)

03/11/20, Captured by Kinfe G/georges

Fig.3.7 Sieved aggregate (NCA)

03/11/20, Captured by Kinfe G/georges

Fig.3.8 Filler (demolished concrete waste dust)

3.4.2. Aggregate Crushing Value (ACV) test

Aggregate crushing value was conducted as per BS 112 part 110; 4700gm sample was prepared and divided into two test specimens was prepared. That surface dry aggregates passing 12.5 mm and retained on 10 mm. The selected 3.25 kg aggregate required for one test sample and cylindrical measure filled with aggregates in 3 layers and tamping each layer 25 times after leveling the aggregates at the top surface. The test sample is weighed and the cylinder is now placed on the base plate.

28/10/20, Captured by Dejeni Derji *28/10/20, Captured by Dejeni Derji*

Fig.3.9 ***Aggregate crushing value (ACV) test for both DCWA &NCA***

3.4.3. Specific Gravity and Water absorption

The specific gravity of aggregate size (i.e. coarse, intermediate and fine) for natural aggregate and (coarse aggregate size) for demolished concrete waste aggregate is done as per AASHTO T 84 & AASHTO T 85 for fine and course aggregates respectively. In this definition fine aggregates are the aggregate size less than 4.75mm sieve size and coarse aggregates are greater than 4.75mm. This test was conducted for bulk specific gravity (dry and saturated surface dry) and apparent specific gravity. Usual procedures were followed to conduct the test coarse aggregate for demolished waste concrete and fine and coarse aggregates for natural aggregates.

3.4.4. Los Angeles Abrasion (LAA) Test

Los Angeles Abrasion is a measure of wearing/degradation capacity of the aggregate by revolving the aggregate in rounded steel container and impacted by steel balls. This test was conducted as per AASHTO T 96/ ASTM C131 test procedures. Since the nominal aggregate size was 19 mm, grading A was chosen for testing LAA.

3.4.5. Aggregate Impact Test

This test assesses the suitability of aggregate as regards the toughness for use in pavement construction road aggregates subjected to pounding action due to traffic loads- so possibility of breaking should be tough enough- so proper aggregates to be used suitability to be checked by laboratory tests.

28/10/20, Captured by Dejeni Derji

28/10/20, Captured by Dejeni Derji

Fig .3.10.Aggregate Impact Test for both DCWA &NCA

3.5. Bitumen quality test

Bitumen quality tests were conducted to determine the specific properties of the bitumen used. Solubility in Trichloroethylene, Flash Point, Penetration at 25oC, 100g, 5sec, Ductility at 25oC,Penetration of residue percent of original, at 25oc,100g, 5sec, Ductility of residue, at 25oC, Softening Point & Specific gravity at 25oC were determined. All the tests were conducted in accordance with AASHTO materials Test specification. No special procedures or considerations were taken for bitumen quality tests. Every test stated above was conducted in triplicate to get more precisions.

3.5.1. Solubility test

This test was conducted in accordance with AASHTO T 44. The principle for the test is to determine the solubility of asphalt in Trichloroethylene in which the portion that is soluble in Trichloroethylene represents the active cementing constituents.

The method is summarized as: the asphalt sampled for this method was dissolved in trichloroethylene and filtered through filter mat and the insoluble material was washed, dried and weighted. Calculation was done as:

$$\text{Soluble percent} = 100 - \left(\frac{A}{B} * 100\right) \text{------------------}3.6$$

Where:

A- total mass of insoluble

B- Total mass of sample

3.5.2. Flash Point Test

This test was conducted as per ASTM D 92-96 test procedures. The flash point of the sampled asphalt was determined by using open apparatus. About 70ml of sample was taken and filled to the cup and raised the temperature by constant provision of flame around the cup using cylinder filled with oxygen gas. Thermometer was mounted to measure the temperature. The temperature was measured and recorded where some ignition of the asphalt was observed. And this temperature is recorded as flash point. The significance of this test was to know the flammability risk of the bitumen during mixing or handling.

3.5.3. Penetration Test

This test was conducted in accordance with ASTM D 5-95 test procedures. The penetration test is used as a measure of consistency. The naming of bitumen 60/70 is adopted from the value of penetration. This means the penetration value is in range of 60-70.

3.5.4. Ductility at 25^{0}C

The test procedures for ductility test were referred from AASHTO T 51-00/ASTM D 113-99.The test gives information about the tensile performance of bitumen.

3.5.5. Softening Point

Softening point test was conducted by following the procedures specified in AASHTO T 53-96/ ASTM D 36-95. This test was conducted to determine the melting point of bitumen in subject since the viscoelastic property does not allow determining the exact point of melting. Ball and ring apparatus was used to know the softening point.

3.6. Marshal Mix design

The Marshall method of design was originally developed by Bruce Marshall, formerly of the Mississippi Highway Department, and improved by the U.S Army Corps of Engineers. The Marshall method is applicable only to hot mix asphalt using penetration, viscosity or PG graded asphalt binder or cement and containing aggregate with maximum size of 25.0 mm (1in.) or less. The purpose of marshal method is to determine the optimum asphalt content for a particular blend of aggregate. And also provide information about the properties of the resulting pavement mix, including density and void content, which are used during pavement constriction.

The main purpose of the study is to investigate that demolished concrete waste aggregate could serve in hot mix asphalt as coarse aggregate material for flexible pavement road.

Towards this goal many laboratory studies had been conducted .100% Natural crushed aggregate was used in hot mix asphalt for control mix design and the Marshall Mix design procedures were followed. Then additional mixes were prepared by blending demolished concrete waste aggregate with natural crushed aggregate in proportions of: 0:100 %, 25:75%, 50:50% and 75:25% (DCWA :NCA).The percentage of composition was taken randomly and to deviate from some literatures which conducted the blending up to 40% and 60% for recycled concrete aggregate.

The procedures, methods and methodologies were described below. The Marshall method uses standard test specimen 64 mm (2.5 in) height and 102 mm (4 in.) internal diameter. A series of specimens, each containing the two blended aggregate and varying in asphalt content from 4 % to 6 % (by weight of total mix) for control mix and for the replacement mix the bitumen content varies with the percentage of DCWA increase with increment of 0.5% depending on Asphalt Institute Manual series recommendations. The marshal test procedures have been standardized by the ASTM and published as ASTM D1559.

The test procedure starts with the preparation of test specimens, and steps preliminary to specimen preparations are:-

- ❖ All materials proposed to use would meet the physical requirement of the specification.
- ❖ Aggregate blend combination meets the graduation requirements of the specification.
- ❖ Determine the bulk specific gravity of all aggregate used in the blend and the specific gravity of asphalt cement for performing density and void analyses.

3.6.1. Aggregate gradation

Aggregate grain size distribution or gradation is one of the properties of aggregates which influence the quality of hot mix asphalt. The coarse, intermediate and fine aggregate particles were separated into different sieve size and proportioned to obtain the desired gradation for bituminous mixtures of ASTM 3515.

As it is mentioned earlier that aggregates from crusher site was delivered in three different sizes (< 6, [6-13), [13-19).The physical properties of aggregates were tested and no refrain from usage according to specification were found. Hence the aggregates were blended in order to attain the gradation limit of fullers 0.45 power chart.

The blending were done on excel spread sheet with trial and error method. Two gradations were prepared with varying amount of conventional mineral filler content. The first gradation was prepared with 5.5% crushed dust filler (by weight of aggregate), the second gradation was prepared with 6.5% crushed dust filler (by weight of aggregate) using of purposive sampling method

3.6.2. Preparation of specimens for hot mix asphalt mixture

The mix design was prepared following the right procedures specified and prescribed in ERA flexible pavement design manual and Asphalt Institute Manual Series (MS-2). Materials are needed to prepare HMA mixture specimens were: - blended and oven dried aggregates, bitumen 60/70 penetration grade heated up to 150-170^{0}c, heated mold with collar, balance sensitive to 0.1gram, oven, Marshall compaction machine, mixing bowl, spatula, filter paper and pan are the main materials used for preparing the HMA mixture specimens.

To prepare the HMA mixture specimen the following procedures were done.

- ❖ 1200g blended aggregates were dried in oven with a temperature of 160-170 for minimum of 16 hours and bitumen also heated by 150-170^{0}c.
- ❖ Materials which had contact with the mix were heated in oven for a minimum of 8 hours before mixing was started.
- ❖ For each gradation trial bitumen was added in required quantity i.e. 4 %, 4.5 %, 5% and 5.5% (by weight of total mix).
- ❖ The heated aggregates and bitumen are weighted and mixed by hand properly until a homogeneous mix is obtained with controlled temperature as shown Fig-3.11.

- The mixed mixtures were placed in the preheated Mold and the compactions of the specimens were done with automated equipment by adjusting number of blows 75 by assumption for heavy traffic.
- The specimens were compacted 75 blows in each side of the specimen with the standard Marshall hammer as specified in ASTM D1559. .

02/11/20, Captured by Kinfe G/georges *03/11/20, Captured by Dejine Derji*

Fig. 3.11 Aggregates dried in oven and weighting of bitumen

02/11/20, Captured by Hachalu Kebed *02/11/20, Captured by Hachalu Kebed*

Fig - 3.12.Mixing of materials and compaction.

After 24 hours the specimens were removed from the mold by using specimen extruder as shown below in Fig 3.13. The specimens were then weighed dry in air, weighed in water and saturated surface dry weight for determining the bulk specific gravity of the specimen. After the specimens were weighed in air, water and saturated surface dry weight they were put in the water bath with a temperature of 60 for 30 minutes,

20/11/20, Captured by Hachalu Kebed   *20/11/20, Captured by Hachalu Kebed*

Fig. 3.13.Extrution of compacted specimen after 24hr

3.6.3. Testes for volumetric analysis

Marshall Mix design was developed majorly for determining the volumetric properties of hot mix asphalt and strength tests (i.e. Marshall Stability and flow). In order to determine the volumetric properties the parameters to be determined with laboratory testing are specific gravities (bulk specific gravity and maximum theoretical specific gravity).

3.6.3.1. Determination of bulk specific gravity

The compacted specimens were properly labeled and extracted after sufficient cooling Weights for each specimen for dry condition were recorded. This test was conducted as per AASHTO T 166/ASTM D 2726-93 a standard test method for bulk specific gravity and density of compacted bituminous mixtures using saturated surface dry specimen.

(a) *(b)* *(c)*

20/11/20, Captured by Hachalu Kebed *21/11/20,Captured by Hachalu Kebed*

Fig. 3.14. Air dried weight (a), SSD weight (b) and (c) spacemen in water bath

The standard procedure for determining the bulk specific gravity of compacted asphalt concrete involves weighing the specimen in air and in water. The bulk specific gravity (**GMB)** of a compacted mix is equal to:

$$Gmb = \frac{A}{B - C} ---------- 3.7$$

Where:-

GMB =Bulk specific gravity of compacted specimen

A=Mass of dry specimen in air (g).

B=Mass of saturated surface dry specimen in air (g).

C=Mass of specimen in water (g).

3.6.3.2. Marshall Stability and Flow

The specimen were removed from the water bath and placed quickly in the Marshall Stability and flow testing machine. The flow meter or deformation measuring dial gauge is placed in position and adjusted to read zero. The load is applied through the Marshall Test setup. Maintaining a constant deformation rate of 50.8 mm per minute, the minimum load is failure (stability) and the corresponding deformation (flow) readings are carefully noted.

27/11/ 20, Captured by Dejni Dreji *27/11/ 20, Captured by Dejni Dreji*

Fig. 3.15.Marshal Test apparatus seat up and (stability and flow) test in progress

3.6.3.3. Determination of maximum theoretical density (Gmm)

This is also density measuring parameter to determine the air void which in turn used to determine level of compaction of hot mix asphalt. Theoretical maximum density was conducted in accordance with ASTM D 2041. This test was conducted for un-compacted lose state mixture and also checked from the compacted mixture since literatures stated that the gradation change during mixing also affect the value of maximum theoretical density. But in this research no significant difference was observed. Theoretical maximum specific gravity is the ratio of the weight in air of a unit volume of un compacted bituminous paving mixture at a stated temperature to the weight of an equal volume of gas free distilled water a stated temperature. The maximum specific gravity (G_{mm}) at different asphalt contents was measured to calculate air voids.

26/11/20, Captured by Dejni Dreji (a) *26/11/20, Captured by Dejni Dreji (b)*

Fig. 3.16.Waighting los state mixture (a) and Vacuum application for saturated sample (b)

The theoretical maximum specific gravity of a mix is defined as: -

$$Gmm = \frac{A}{(A+B)-C} ----------- 3.8$$

Where:-

GMM = Maximum theoretical specific gravity is calculated as per ASTM D2041

A= Mass of the dry sample in air (g).

B= Mass of jar filled with water (g).

C= Mass of jar filled with water + sample (g).

3.6.4. Volumetric properties of HMA mixture

Volumetric analysis of hot mix asphalt was done in order to know the degree of compaction and to determine the optimum bitumen content. Void in total mix (Air Void), Void in mineral aggregate (VMA), Void filled with asphalt (VFA) & effective asphalt content (Pbe) was determined through analytical approach from the specific gravities determined via test. The methodology for calculation of each parameter is discussed below.

3.6.4.1. Air void (VA)

According to (Asphalt Institute,2003), the total volume of the small pockets of air between the coated aggregates particles throughout a compacted paving mixture, expressed as percent of the bulk volume of the compacted paving mixture. The air voids, Va, in the total compacted paving mixture consists of the small air spaces between the coated aggregates particles. The voids in a compacted mixture are obtained in accordance with ASTM D3203- 94 standard test method. The voids in a compacted mixture are obtained as follows.

$$Va = \left[\frac{(Gmm - Gmb)}{Gmm}\right] * 100 ----------- 3.9$$

Where:

VA = Air voids in compacted mixture.

GMM = Maximum specific gravity of paving mixture.

GMB =Bulk specific gravity of compacted mixture.

3.6.4.2. Voids in mineral aggregate (VMA)

According to (Asphalt Institute, 2003), the voids in the mineral aggregates, are defined as the inter-granular void space between the aggregate's particles in compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume of the sample. The VMA are calculated based on the bulk specified gravity of the aggregates and is expressed as a percentage of the bulk volume of the compacted paving mixture. It is calculated as:

$$VMA = \left[100 - \frac{(Gmb * Ps)}{Gsb}\right] * 100 ---------- 3.10$$

Where:-

VMA=Voids in the mineral aggregate.

GMB = Bulk specific gravity of total aggregate.

GSB = Bulk specific gravity of total aggregates.

PS =aggregate content, percent by mass of total mixture.

3.6.4.3. Voids filled asphalt (VFA)

According to Asphalt Institute 2003, the percentage portion of the volume of inter-granular Void space between the aggregate particles that is occupied by the effective asphalt content. It is expressed as the ratio of (VMA-VA) to VMA. The voids filled asphalt, VFA is the percentage of the integral void space between the aggregate particles (VMA) that are filled with asphalt. The mathematical relationship has shown as:

$$VFA = \left[\frac{(VMA - VA)}{VMA}\right] * 100 ---------- 3.10$$

Where:

VFA=Voids filled with asphalt, percent of VMA.

VMA= Voids in mineral aggregate, percent of the bulk volume.

VA = Air voids in compacted mineral, percent of total volume.

3.6.4.4. Effective asphalt content (Pbe)

The effective asphalt content **Pbe** in the paving mixture is the total asphalt content minus asphalt quantity absorbed by the aggregates. Effective asphalt content governs the performance of asphalt paving mixture. The effective bitumen content for the paving mixture prepared in laboratory for this research is calculated and presented in the next chapter.

3.6.5. Determination of bitumen content

Principally The objectives for Marshall Mix design of HMA are:

i. To have sufficient asphalt in the mix to endure durable pavement.
ii. To get a mix with adequate stability to satisfy the demands of traffic without distortion or displacement.
iii. To have voids content high enough to allow for a slight amount of compaction under traffic loadings without flushing, bleeding and loss of stability, yet low enough to keep out harmful air & moisture.
iv. Sufficient workability to permit efficient placement of the paving mixture without segregation.

Accordingly to achieve the objectives mentioned above the bitumen content optimization is the sole solution. The bitumen content in this research was determined as per Asphalt Institute MS-2 and with NAPA (National Asphalt Pavement Association) method and compared the values from both methods and the bitumen content which satisfies all the criteria was adopted. Formerly analyzed values were plotted in graph of best fits plot in excel spreadsheet. The plot includes: Stability vs. Bitumen Content, Flow vs. Bitumen Content, Unit weight of total mix vs. Bitumen Content, Percent air voids vs. Bitumen Content, Percent VMA vs. Bitumen Content & Percent VFA vs. Bitumen Content. After plotting of the points for each various bitumen contents, two methods were followed to determine the maximum bitumen content.

Method 1: bitumen content at 5% of air void was determined and this bitumen content was checked for the other parameters whether the specification requirement is fulfilled or not.

Method 2: bitumen content at maximum stability, bitumen content at 5% air void and bitumen content at maximum density was determined and the values of the three bitumen content was averaged. This bitumen content was evaluated for other voids, stability and flow parameters whether the specifications requirements are satisfied or not. The bitumen content from the two methods was compared. The minimum among the two values were the one computed with method 2, but this bitumen content does not fulfill the requirement of air voids and VFA. Hence bitumen content determined from method 1 (at 5% air void) was adopted as optimum bitumen content.

3.6.6. Indirect tensile strength Test

This test was conducted to determine the potential damage of hot mix asphalt due to moisture induced damage. This test is not customary in our country even specifications are provided in the manual. Demolished concrete waste aggregate is highly water absorptive, when the hot mix asphalt with this type of aggregate is exposed to moisture, stripping will be occurred (i.e. the bitumen will detach from the aggregate and water will intrude to the compacted mix and the mix will be prone to moisture damage. ITS test was conducted to measure the performance of the mix that will show on site when exposed to the severe condition. ITS test was conducted in accordance with AASHTO T 283-89(1993) resistance of compacted bituminous mixture to moisture induced damage. Generally the test covers preparation of specimens and measurement of the change of diametric tensile strength resulted from the effects of saturation and accelerated water conditioning of compacted bituminous mixtures in laboratory. The result was used to predict the long term stripping susceptibility of bituminous mixtures.

03/12/20, Captured by Kinfe G/georges *(a)* *03/12/20, Captured by Kinfe G/georges* *(b)*

Fig. 3.17.Conditiond specimen (a) and UN conditioned (dry) specimen (b)

03/12/20, Captured by Kinfe G/georges (a) 03/12/20, Captured by Kinfe G/georges (b)

Fig. 3.18.ITS testing step (a) and ITS test result reading (b).

CHAPTER - 4

RESULTES AND DISCUTION

This chapter includes the analysis of all results and discussions that obtained from the laboratory test. The laboratory test results for physical properties of materials used in hot mix asphalt were: - natural crushed aggregate (NCA), demolished concrete waste aggregates (DCWA) and bitumen. The volumetric properties of the replacement and control mix were presented and discussed in this portion.

Laboratory tests were conducted for physical properties of aggregates such as:- grain size analysis, specific gravity and water absorption, Los Angeles Abrasion, Aggregate Crushing value, Aggregate impact value tests and Marshall Mix design for different proportions of demolished concrete waste aggregate with natural crushed aggregate was also conducted. Furthermore tensile strength test were conducted to predict the moisture induced damage of the compacted paving mixture.

4.1. Physical Properties of Aggregates

The physical properties of demolished concrete waste aggregate which was collected from Jimma University main campus and the natural crushed aggregate also collected from ERA Jimm district Asendabo stockpile was tested in laboratory of Jimma University institute of technology.

4.1.1. Particle Size Analysis

The gradation of the aggregate fall in specification limit in the lower bound of the left side (fine sieve sizes) it looks to deviate from lower bound that means the material in analysis seems coarser but the compaction effort will change the gradation to finer since the attached mortar on the aggregate goes to crush. It was found that the change in gradation of aggregates containing DCWA, as coarse aggregates, due to the effect of mixing and compaction is significantly higher than that for fresh basalt aggregate (Paranavithana,S. and Mohajerani,A.,2003.)

4.1.2. Specific gravity and Water absorption

All of the literatures around recycled concrete aggregate revealed that the specific gravity of the RCA is lower than conventional aggregate due to the porosity of the attached mortar on the surface of demolished concrete waste aggregate. The absorption on the contrary is higher than the natural aggregate. This is also due to the attached mortar on the surface of the waste aggregate.

The results of the specific gravities and water absorption for demolished concrete waste aggregate and natural aggregate are listed in table 4.1- 4.4. As it can be observed from the results the water absorption of demolished concrete waste aggregate (DCWA) is greater than that of natural crushed aggregate (NCA). This indicates that the result of the attached mortar on it. The specific gravity of demolished concrete waste aggregate (DCWA) is also less than that of natural crushed aggregate (NCA) as shown in the test result and indicated by the literatures.

Table 4.1 Test result for specific gravity of demolished concrete waste (DCWA)

Specific Gravity of (DCWA)			
Particle Size	Bulk. Specific Gravity (Dry)	Bulk. Specific Gravity (SSD)	Apparent. Specific Gravity
	Average	Average	Average
Coarse Aggregate	2.20	2.40	2.67

Table 4.2 Test result for water absorption of demolished concrete waste (DCWA)

Water Absorption of (DCWA)		
Particle Size	Water Absorption (%)	Standard Specification (%)
	Average	
Coarse Aggregate	9.27	< 2

Table 4.3 Test result for specific gravity of natural crushed aggregate (NCA)

Specific Gravity of NCA			
Particle Size	Bulk. Specific Gravity (Dry)	Bulk. Specific Gravity (SSD)	Apparent. Specific Gravity
	Average	Average	Average
Coarse Aggregate	2.63	2.66	2.72
Fine Aggregate	2.58	2.64	2.74

Table 4.4 Test result for water absorption of natural crushed aggregate (NCA)

Water Absorption of NCA		
Particle Size	Water Absorption (%) **Average**	Standard Specification (%)
Coarse Aggregate	1.27	< 2.00
Fine Aggregate	1.06	< 2.00

When comparison is done between the demolished concrete waste aggregate and natural crushed aggregate in terms of specific gravity and water absorption. The specific gravity of natural crushed aggregate is much greater than the specific gravity of demolished concrete waste aggregate this is due to the presence of light weight mortar in DCWA.

On the contrary the absorption of demolished concrete waste aggregate (DCWA) is greater than the absorption value of natural crushed aggregate (NCA) this is again due to the porosity of mortar which is the cause for deficient properties of such kinds of aggregates.

The limit of specification for maximum absorption as per ERA specification for utilizing the aggregates in hot mix asphalt is 2%. But the result of the tested aggregate deviate much more than the specification. This indicates that utilizing demolished concrete waste aggregate in hot mix asphalt on more water occurring area will cause stripping problem. Yet this was tested with tensile strength test by exposing the compacted paving mixture to water soaking in laboratory. Hence it is not recommendable to use 100% demolished concrete waste aggregate (DCWA) in hot mix asphalt without any treatment.

4.1.3. Los angles Abrasion Value

The mechanical wearing capacity of the aggregate tested by Los Angeles Abrasion exhibit that the demolished concrete waste aggregate is good against abrasion. The specification of ERA sets the maximum value of LAA 30 for bitumen/ cement bounded wearing surface course.

Here the result shows that demolished concrete waste aggregate satisfy the requirement in terms of LAA for hot mix asphalt wearing surface course.

Table 4.5 Los Angles Abrasion (LAA) result for NCA & DCWA

Test	Natural Crushed Aggregate (NCA)	Demolished Concrete Waste Aggregate (DCWA)	Standard Specification	Remark
Average LAAV (%)	12.5%	18.20%	< 30 for asphalt aggregate	Both types of aggregates are under specification limit

4.1.4. Aggregate Crushing Value (ACV)

Aggregate crushing value (ACV) can be used as a quality control test for hot mix asphalt aggregate according to ERA specification. Due to this ACV was conducted for both demolished concrete waste aggregate and natural crushed aggregate to compare both values and to check whether the value of ACV is within specification limit or not. Accordingly the result for this test is presented in table 4.6.It is expected that natural aggregate has more resistance than demolished concrete waste aggregate. For static impact load the demolished concrete waste aggregate unveil good property against the static impact load.

Table 4.6 Aggregate Crushing Value (ACV) Test result for NCA & DCWA

Test Type	Natural Crushed Aggregate (NCA)	Demolished Concrete Waste Aggregate (DCWA)	Standard Specification	Remark
Average Aggregate Crushing Value (ACV) %	19.54	29.78	< 25	DCWA is out of Specification limit for Hot Mix Asphalt.

Table 4.7 Summery of aggregate quality test results and corresponding ERA specifications

Item No	Test Type	Test Method	Materials		Specification for asphalt aggregate
			Natural Crushed Aggregate (NCA)	Demolished Concrete Waste Aggregate (DCWA)	
1	Aggregate Crushing Value (ACV) %	BS 812 Part 110 : 1990	19.54	29.78	Max 25
2	Los Angles Value LAA (%)	AASHTO T-96	12.50	18.20	Max 30
3	Bulk. Specific Gravity (Dry)	(AASHTO T85 - 91)	2.63	2.20	NA
4	Bulk. Specific Gravity (SSD)	AASHTO T85 - 91	2.66	2.40	NA
5	Apparent. Specific Gravity	AASHTO T85 - 91	2.72	2.67	NA
6	Water Absorption (%)	AASHTO T85 - 91	1.27	9.27	Max 3
7	Ten percent fines value (TFV) % Wet	BS 812 Part 110 : 1990	286.12	135.00	
8	Ten percent fines value (TFV) % Dry	BS 812 Part 110 : 1991	312.71	153.00	Min 160
9	Ten percent fines value Ratio (%)	BS 812 Part 110 : 1992	91.50	88.24	

In summary the results for physical and mechanical properties of demolished concrete waste aggregate shows good quality to utilize as asphalt aggregate except the absorption property and the durability problem which were evaluated by TFV and ACV. The Los Angles Abrasion value shows conformance with the specification of ERA.

4.2. Bitumen quality Test

Bituminous binder of grade 60/70 penetration was used in the preparation of mixtures since it is widely used and suitable for hot temperature area like Ethiopia. According to Manual Series –2 (1997), the annual air temperature greater or equal to 24 the asphalt grade is 60/70 penetration grade. From the test results it can be deduced that the bitumen has good quality and can be used in hot mix asphalt. Regarding to this deduction the bitumen was used in marshal mix design for preparation of test specimens.

Table 4.8 Summary of bitumen quality tests results

Test No	AASHTO T 44 Solubility in Trichloro ethylene, (%)	AASHTO T 48 Flash Point, ^{O}C	AASHTOT49 Penetration at 25°C, 100g, 5sec	ASHTOT 51 Ductility at 25°C (cm)	AASHTO T 53 Softening Point (0C)	AASHTO T228-06 Specific gravity at 25°C (kg/m3)
1	99.10	288.00	66.00	147.00	53.00	1.08
2	99.20	298.00	64.00	154.00	55.00	1.10
Average	99.15	293.00	65.00	150.50	54.00	1.09
Standard Specification	>99	>219	60-70	>75	42-51	NA

4.3. Marshall Mix Design

Marshall Mix design was conducted to response the questions on the research objective whether demolished concrete waste aggregate serve as a coarse aggregate in hot mix asphalt or not. If yes what are the unique properties and how it affects the nature of paving mixture. Could it be used by itself only or need blending with natural aggregate to optimize the mixture characteristics, if it requires natural aggregate, how much replacement was give better mix property? How is the trend when the proportion of demolished concrete waste aggregate is increased in replacing the natural aggregate? Hereafter in response towards those and other questions Marshall mix design was conducted for proportions of aggregate percentage of (0% DCWA:100% NCA,25% DCWA : 75%NCA,50% DCWA : 50% NCA & 75% DCWA : 25% NCA).

In Marshall Mix design there are analytical procedures and tests for the analysis in order to determine the optimum bitumen content and to check the volumetric properties of hot mix asphalt as if were in specification limit to be followed. These analytical producers in the delivery of the results and results were presented and discussed below.

4.3.1. Aggregate Gradation Design

Aggregates with different sizes provided was blended to the proportion that falls in the specification limit and resembles to the maximum gradation curves. This proportion was conducted with trial and error method to accomplish the desired gradation curves.

The combined gradation of aggregates and the specification criteria for asphalt binder coarse is summarized in tables 4.7 and 4.8.figure 4.1 and 4.2 shows the two types of gradation on the basis of demolished concrete waste and natural aggregate by weight of total mix. Shows the final proportion of each aggregate material in asphalt binder course and the proposed aggregate gradation curves are shown in fig 4.1 to 4.2 based on ASTM specification for asphalt binder coarse specification.

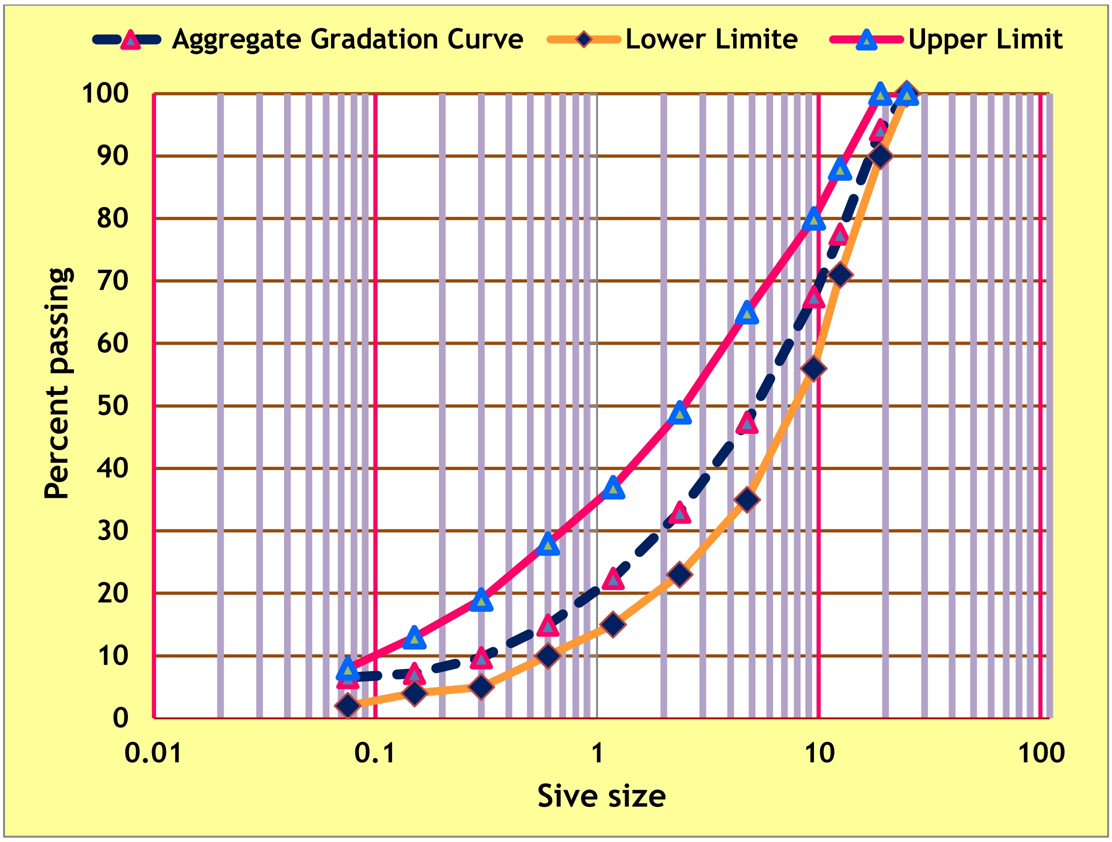


Fig. 4.1.Gradation curve for demolished concrete waste aggregate (DCWA)

Fig 4.1 indicates the curve of gradation that was prepared based on the standard specification of ASTM D3515 limits. In this gradation the aggregates were selected from each size by their limit ranges and the crushed stone dust filler was used by weight of Aggregates. The graph shows three different color lines. The green line indicates the upper limit of ASTM Specification, the red line indicates lower limit of ASTM Specification and the blue line indicates the prepared gradation of demolished concrete waste .The prepared gradation is between the upper and lower limits of ASTM Specification as shown in fig 4.1. Hence the prepared gradation satisfies the specification requirements.

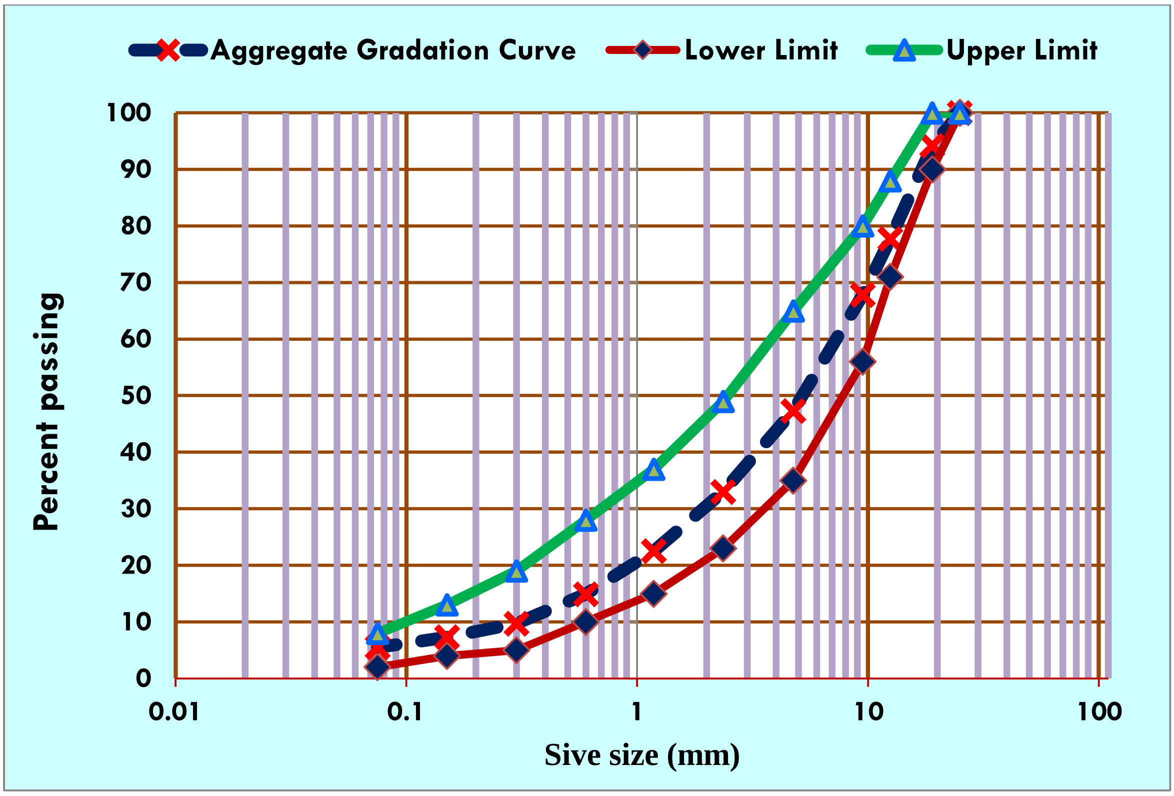


Fig. 4.2.Gradation curve for natural crushed aggregate (NCA)

Fig 4.2 indicates the curve of gradation that was prepared based on the standard specification of ASTM D3515 limits. In this gradation the aggregates were selected from each size by their limit ranges and crushed stone dust filler was used by weight of Aggregates. The graph shows three different color lines. The green line indicates the upper limit of ASTM Specification, the red line indicates lower limit of ASTM Specification and the blue line indicates the prepared gradation of natural crushed aggregate. The prepared gradation is between the upper and lower limits of ASTM Specification as shown in fig 4.2. Hence the prepared gradation satisfies the specification requirements.

4.3.2. Determination of bitumen content

The initial design bitumen content was founded from the formula

$$DBC = 0.035A + 0.045B + KC + F \text{---------------} (4.3)$$

Where:

A = percent of aggregate retained on sieve no 2.36 mm

B = percent of aggregate passing on sieve no 2.36 mm and aggregate retained on 0.075mm

C = percent of aggregate passing on sieve no 0.075 mm

K = 0.15 for 11-15% passing 0.075 mm sieve, 0.18 for 6-10% passing 0.075 mm sieve, and 0.20 for 5% or less passing 0.075 mm sieve. However the bitumen content for demolished concrete waste aggregate was 6.44 ~ **6.5** by taking F=2, but this number was the initial and the design bitumen content for natural aggregate was **5.1** by considering F=0.7, but in actual sense these values are significantly different.

4.3.3. Bulk Specific gravity of compacted mixture (Gmb)

After preparation of specimens for five different bitumen contents by mixing and compaction, bulk specific gravities of each specimen were determined for different proportion of demolished concrete waste aggregate and natural aggregates. The bulk specific gravity is determined for each specimen at 25°C in accordance with the test procedure described in ASTM D2726.

Table 4.9 Test result for bulk Specific gravity of compacted mix (Gmb)

Bulk Specific gravity (Gmb)												
Bitumen Content (%)	DCWA 0%			DCWA 25%			DCWA 50%			DCWA 75%		
	T-1	T-2	Average	T-1	T-2	Average	T-1	T-2	Average	T-1	T-2	Average
4.0%	2.18	2.17	2.17									
4.5%	2.24	2.24	2.24	2.17	2.17	2.17						
5.0%	2.27	2.27	2.27	2.23	2.22	2.22	2.06	2.06	2.06			
5.5%	2.27	2.26	2.26	2.26	2.26	2.26	2.16	2.16	2.16	2.15	2.00	2.07
6.0%	2.21	2.21	2.21	2.26	2.26	2.26	2.19	2.18	2.18	2.07	2.06	2.07
6.5%				2.22	2.20	2.21	2.21	2.19	2.20	2.16	2.10	2.13
7.0%							2.18	2.22	2.20	2.08	2.10	2.09
7.5%										2.09	2.04	2.06

4.3.4. Theoretical maximum specific gravity of lose mixture (Gmm)

Maximum specific gravities were determined at two bitumen contents and the remaining was calculated from the formula correlated with effective specific gravity of the aggregate. Table 4.12 presents maximum and table 4.13 presents bulk specific gravity results of the paving mixtures at different proportions.

Table 4.10 Test result for theoretical Maximum Specific gravity (Gmm)

Theoretical Maximum Specific Gravity (Gmm)												
Bitumen Content (%)	DCWA 0%			DCWA 25%			DCWA 50%			DCWA 75%		
	T-1	T-2	Average	T-1	T-2	Average	T-1	T-2	Average	T-1	T-2	Average
4.0%	2.44	2.41	2.43									
4.5%	2.40	2.38	2.39	2.44	2.39	2.42						
5.0%	2.36	2.37	2.36	2.44	2.39	2.42	2.36	2.39	2.38			
5.5%	2.36	2.38	2.37	2.38	2.39	2.39	2.39	2.39	2.39	2.38	2.39	2.39
6.0%	2.36	2.38	2.37	2.36	2.37	2.37	2.38	2.36	2.37	2.38	2.39	2.39
6.5%				2.38	2.39	2.39	2.39	2.39	2.39	2.36	2.35	2.36
7.0%							2.35	2.38	2.37	2.35	2.39	2.37
7.5%										2.39	2.39	2.39

4.4. Volumetric properties analysis results

From the results of specific gravities presented above, volumetric analyses are done. The volumetric analysis includes the voids in total mix; air void (Va), the voids in mineral aggregate (VMA), the voids filled with asphalt (VFA), effective bitumen content and absorbed bitumen. The results are shown in table 4.11 for different aggregate proportions of the mix.

Bitumen Content %		4.0%	4.5%	5.0%	5.5%	6.0%	6.5%	7.0%	7.5%
Average Air Void (VIM) %	DCWA 0%	**10.41**	**6.31**	**5.00**	**4.94**	**4.71**			
	DCWA 25%		10.06	7.97	5.00	4.47	4.27		
	DCWA 50%			**13.39**	**9.58**	**7.81**	**7.37**	**5.00**	
	DCWA 75%				15.82	13.30	11.03	9.74	5.00
Average VMA (%)	DCWA 0%	**20.11**	**18.22**	**18.37**	**18.49**	**18.71**			
	DCWA 25%		20.61	18.79	18.11	18.72	18.99		
	DCWA 50%			**25.22**	**21.85**	**21.45**	**21.28**	**20.72**	
	DCWA 75%				27.69	25.61	24.99	24.10	21.91
Average VFA (%)	DCWA 0%	**48.25**	**65.33**	**72.78**	**73.29**	**74.82**			
	DCWA 25%		51.21	57.59	72.39	76.15	68.90		
	DCWA 50%			**46.89**	**55.60**	**62.06**	**65.37**	**76.07**	
	DCWA 75%				42.88	48.07	54.45	59.58	77.20
Average Stability (KN)	DCWA 0%	**8.25**	**9.55**	**9.40**	**8.50**	**6.67**			
	DCWA 25%		9.28	8.56	8.43	8.73	9.21		
	DCWA 50%			**10.36**	**10.21**	**9.88**	**9.20**	**8.79**	
	DCWA 75%				7.96	8.07	8.18	7.45	6.86
Average Flow (mm)	DCWA 0%	**3.37**	**3.37**	**3.50**	**3.53**	**3.99**			
	DCWA 25%		3.29	3.34	3.35	3.55	3.85		
	DCWA 50%			**4.33**	**4.28**	**4.46**	**4.94**	**4.60**	
	DCWA 75%				4.73	5.25	5.19	5.20	5.85

Table 4.11 Volumetric Properties results of deferent percent replacement.

Using these results and the results from stability and flow test graphical plots were drawn in spreadsheet which will best fit. The plots for each proportions of aggregate mix and for each properties analyzed and tested are presented through fig 4.11-4.16

4.4.1. Air void in total mix (VA %)

The air void decreases as bitumen content increases. The air voids increases when the proportion of DCW aggregate increases. This trend of air void is also reported by the researches (Paranavithana&Mohajerani,2003;a.R.R.Pasandín & Pérez,2013;A.R.Pasandín & Pérez,2014;Pérez et al.,2012). The attribute for this trend of air void will be due to the absorptive properties of the porous portion which will create thicker film thickness which in turn hinders the interlocking of aggregates. In addition to this at a time of compaction, the attached mortar will be detached from the natural aggregate which will in turn add the fishers from the crushed mortar. This detached mortar also will not absorb bitumen and left Uncompact in the mix since there is no binding bitumen. Fig 4.3 shows one of the volumetric properties of mix (air void) for the replacement percentage of demolished concrete waste aggregate with natural aggregate of 0% DCWA, 25% DCWA, 50% DCWA and 75% DCWA with different bitumen content.

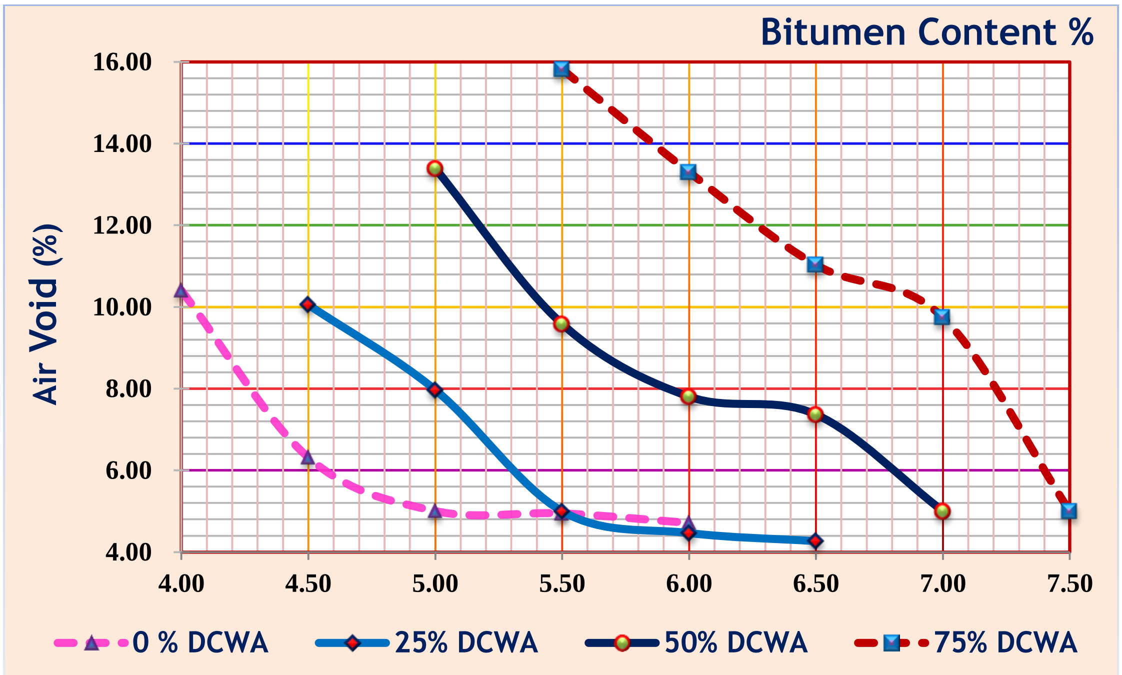


Fig. 4.3.Air Void vs. Bitumen Content

4.4.2. Void in mineral aggregate (VMA %)

VMA is the total volume of voids within the mass of the compacted aggregate. Initially the VMA decreases as bitumen content increases since the voids are filled with bitumen and reach to some minimum infliction point and start to increase.

The cause for increment of VMA when the bitumen increases in excess of absorbed bitumen and the effective bitumen which fills inter granular voids between the particles is the thick film thickness. This film thickness hinders the aggregate to bind each other and this will increase the voids in mineral aggregate. The same result is found as some literatures indicate (Bhusal & Wen, 2013; Mills-Beale & You, 2010) as the content of RCA increases the VMA and VFA decreases. VMA in natural aggregate mix shows consistent variation and less than VMA in crushed concrete aggregate mixes at lower content of RCA. In demolished concrete waste (DCW) aggregate the VMA is higher at 25% DCW aggregate and the other 50% & 75% has lower minimum value and also higher variation in constant bitumen content. The void space due to porosity of the RCA will be the possible cause to increases the VMA.

The angularity of DCWA will lead to the lesser VMA when DCWA increases. Inter granular matrix between the natural aggregate and demolished concrete aggregate will had significant effect on volumetric properties of the paving mixture.

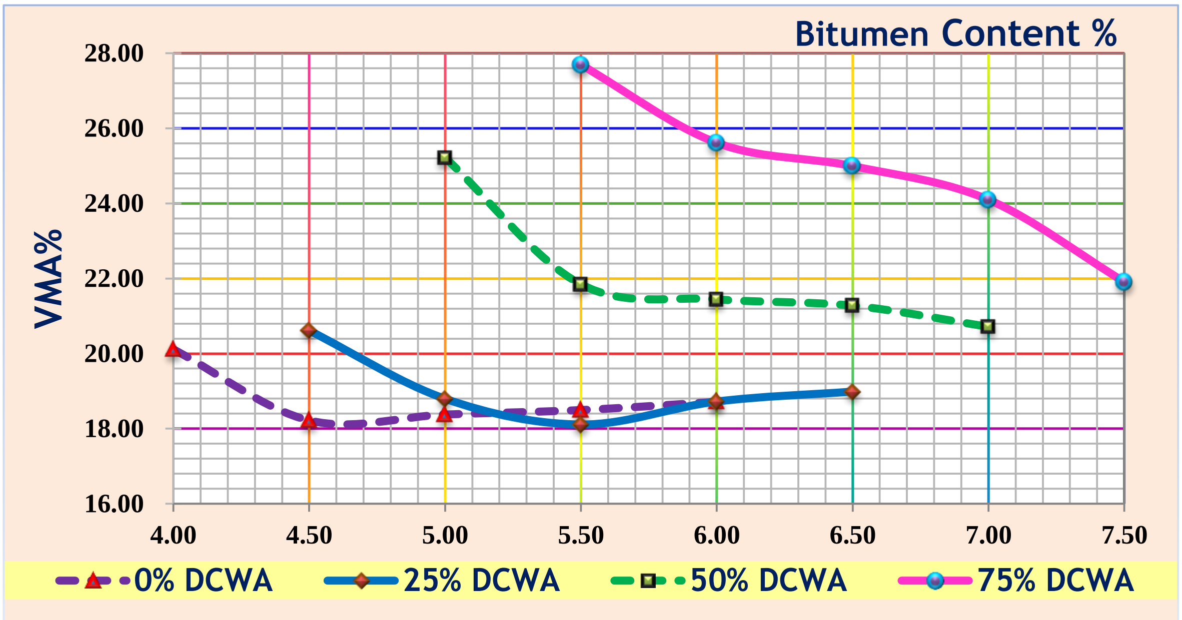


Fig. 4.4.Voids in Mineral Aggregate (VMA) vs. Bitumen Content

4.4.3. Voids Filled with Asphalt (VFA %)

VFA is the void in mineral aggregate excluding air void. This value increases linearly with bitumen content increase. The VFA deceased when the percentage of DCWA increases in the mix this is also mentioned by (Bhusal & Wen, 2013; Mills-Beale & You, 2010). This is due to the absorption value of DCWA increment and thicker film thickness with DCWA amount.

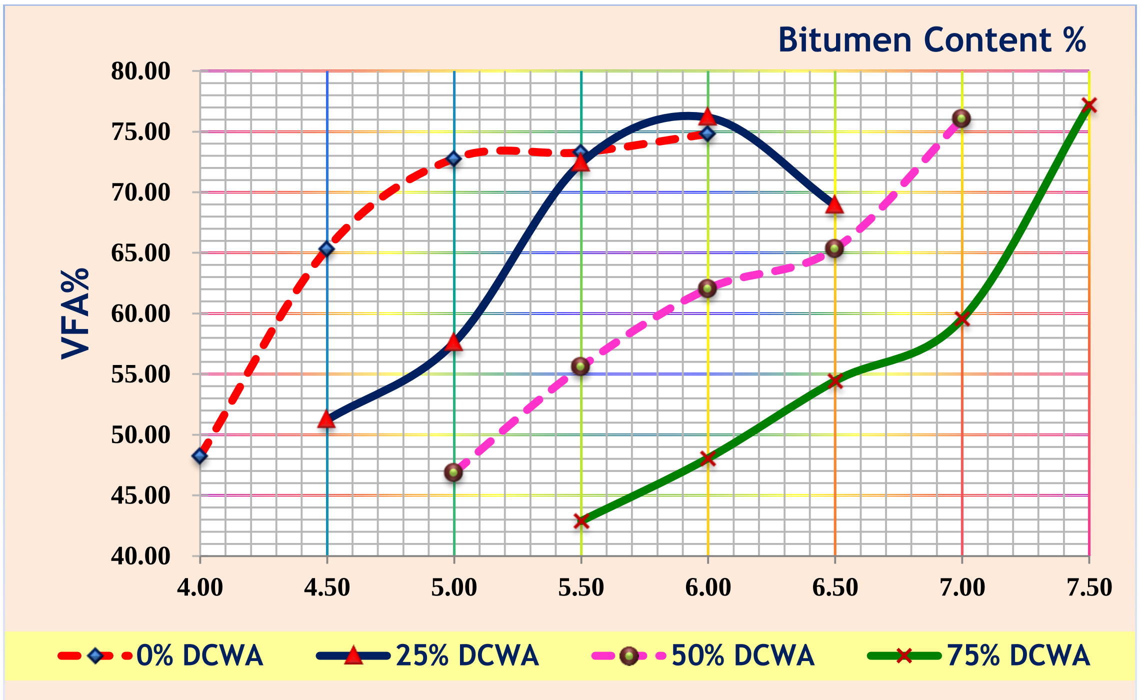


Fig. 4.5.Voids Filled with Asphalt (VFA) vs. Bitumen Content

4.4.4. Stability (KN)

Stability is the ability of the bituminous mixture to resist excessive permanent deformations. The normal trend of stability in Marshall Mix increases with increasing asphalt content, reaches a peak point and then decreases. The stability of natural aggregate mixture is less than DCWA incorporated mixes as also investigated by (Pérezetal.,2012;Wong, Sun & Lai D.,2007) even if the other literatures obtained opposite result and the other obtained similar stability value with natural aggregate asphalt. Stability increases as the percentage of DCWA and the bitumen content increases in the mixture. But at 75% DCWA the stability shows lower value than 25% & 50 % DCW. The curve of stability at 25% DCWA shows opposite trend of the natural aggregate. Curing for 3hrs was tested at 6.4% bitumen content and 75% DCWA for the difference in stability.

The result shows that stability increases when curing for hrs. Increase Stability for cured mixture is increase and for normal mix decrease**.** But on the contrary, void in a mix increases. The possible cause for increment of stability will be the air void in the mix, which will allow to deform before rupturing. The angularity of crushed concrete aggregate will also had substantial effect on the stability property.

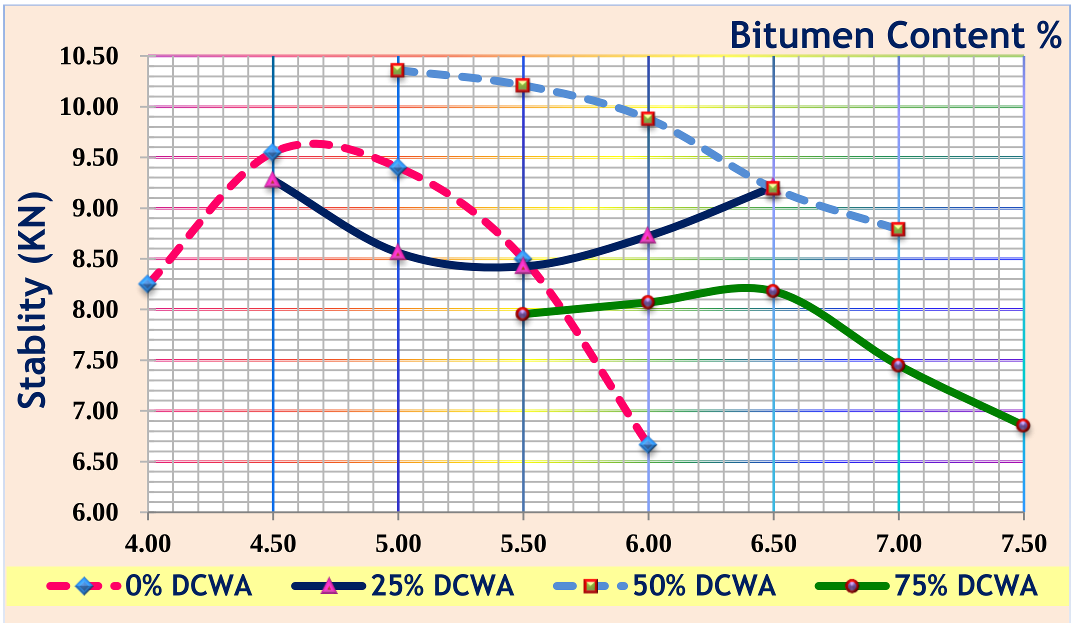


Fig. 4.6.Stablity vs. Bitumen Content

4.4.5. Flow (mm)

Flow increases when asphalt content increases. High flow indicates plastic mix which will be prone to permanent deformation. While low flow indicates brittle mix. The flow value increases while incorporation of demolished concrete waste aggregate increases. This is due to the increase in bitumen for DCWA incorporated aggregate. Flow at 75% DCWA increases highly compared to 50% DCWA with the same bitumen content. This is due to the absorptive property of DCWA. At 75% DCWA absorption of bitumen is higher than 50% DCWA. Hence the unabsorbed bitumen is the cause to greater flow.

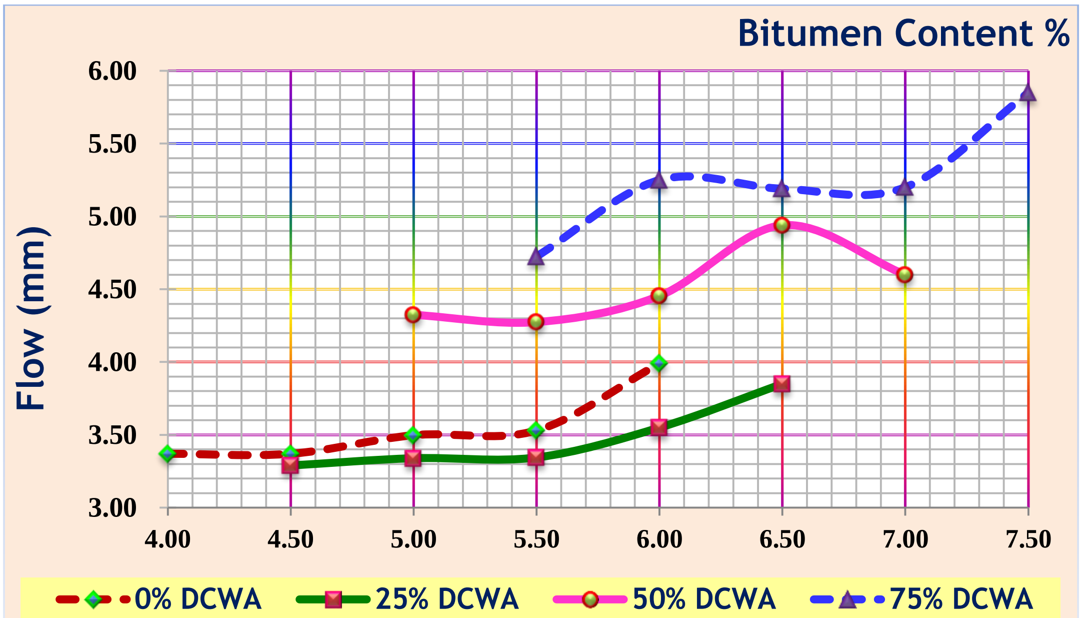


Fig. 4.7.Flow vs. Bitumen Content

4.4.6. Bulk Specific Gravity of mix (g/cm^3)

After preparation of specimens for five different bitumen contents by mixing and compaction, bulk specific gravities of each specimen were determined for different proportion of demolished concrete waste aggregate and natural aggregates. The maximum specific gravities were determined at five bitumen contents. Table 4.10 presents maximum theoretical specific gravity (Gmm) and table 4.9 presents bulk specific gravity results of the paving mixtures at different proportions. Fig 4.8 indicates the relationship between Bulk-density value, the replacement rate of demolished concrete waste and bitumen content of the mix. Bulk density was increases with percentage rate of demolished concrete waste replacement increases.

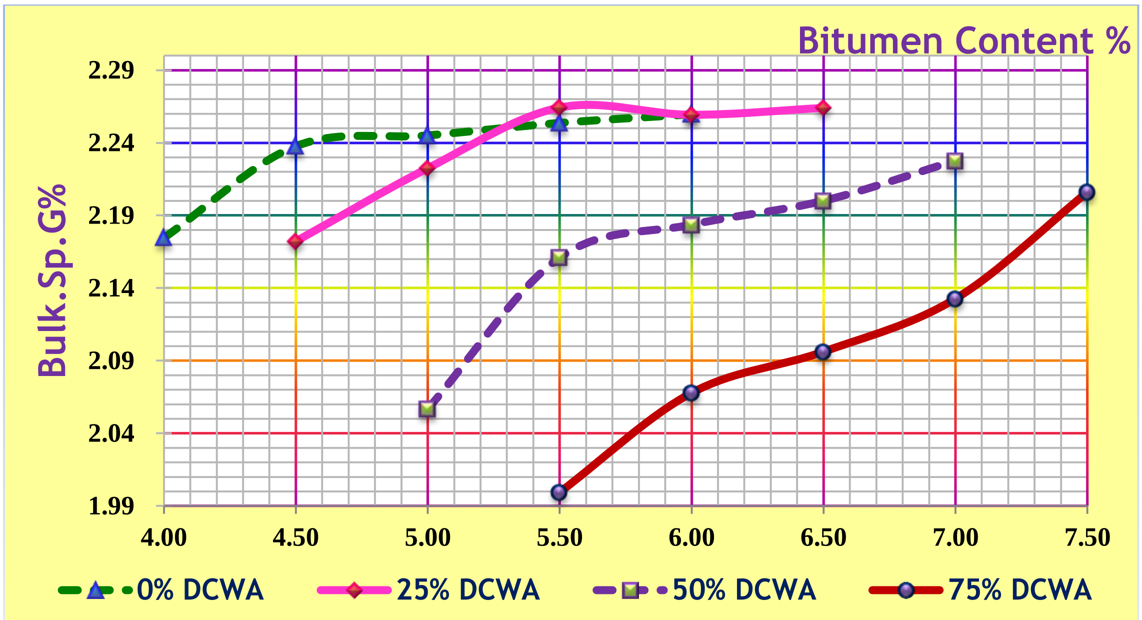


Fig. 4.8.Bulk.Spe.Gravity vs. Bitumen Content

4.5. Determination of design bitumen contents

From the charts above the design bitumen contents are determined for each type of paving mixture. The design bitumen content is determined in two methods: Asphalt Institute method (MS-2) and NAPA method. In NAPA method the asphalt content is determined at the mid specification of air voids (in most specifications 4%), here ERA specifies for heavy traffic 5% air voids. Hence at 5% air void bitumen contents are taken and the other criteria are checked. When demolished concrete waste aggregate increases in the mix the optimum bitumen content increases. The VMA, VFA & stability criteria in accordance to ERA specifications are met for every paving mixture in analysis. But flow and stability are out of the specification limit of ERA for 50% & 75% DCWA.

The result of bitumen content at 5% air void is shown in Fig 4.4 below. The second method, asphalt institute method is determining the bitumen content at maximum stability, determining the bitumen content at maximum density and the bitumen content at 5% air void and these three values were averaged. Even if the bitumen content in this method is lower than the first one the VFA & air void in DCWA incorporated mix does not satisfied the specifications.

	(DCWA) Replacement Percentage				ERA Specification		Asphalt Institute Limit		Remark
	0% DCW	25% DCW	50% DCW	75% DCW	Lower Limit	Upper Limit	Lower Limit	Upper Limit	
Design Bitumen Content (%)	4.8	5.5	7.3	7.5	4.0	10.0	4.0	10.0	ok
Air Void (VA %)	5.0	5.0	5.0	5.0	3.0	5.0	3.0	5.0	ok
VMA (%)	18.4	18.1	20.7	21.9	Min 14	-	Min 14	-	ok
VFA (%)	72.8	72.4	76.1	77.2	65.0	75.0	65.0	75.0	50% & 75% DCWA is out of the spec
Stability(KN)	9.4	8.4	8.8	6.9	Min 7	-	Min 8	-	50% & 75% DCWA is out of the spec
Flow (mm)	3.5	3.3	4.6	5.9	2.0	4.0	2.0	3.5	50% & 75% DCWA is out of the spec
Bulk .Sp. Gravity (%)	2.2	2.3	2.2	2.2	-	-	-	-	

Table 4.12 Summery of Marshall Mix test result of volumetric properties and their specification

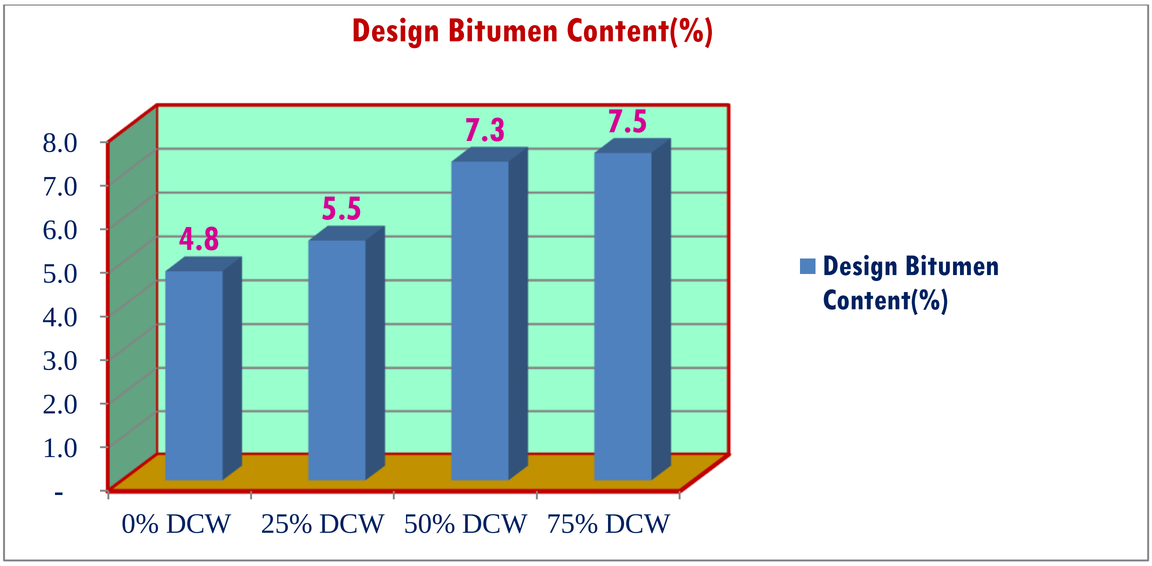


Fig 4.9 Bitumen content at 5% Air void

4.6. Indirect Tensile Strength (ITS) Test Result

This test was conducted to assess the moisture induced damage of the compacted paving mixture. The test was conducted since the absorption of DCWA is higher and the design air void was at maximum limit. This test could characterize the chemical property of bitumen affinity of aggregate. The stripping problem is suspected in demolished concrete waste aggregate due to water loving characteristics of the porous mortar in DCWA. Hence moisture induced damage characterizes this stripping problem of the paving mixture. This test is conducted for 25% & 50% DCWA only since for natural aggregate moisture induced damage is not susceptible and 75% DCWA is not investigated since the absorption property hinders to use 75% DCWA in HMA from quality test. The tests results are shown in table 4.19 & 4.20.

Indirect Tensile Strength(ITS) and Tensile Strength Ration (TSR) For 50 % DCWA										
Sample	DCWA %	Sample No	Spec. (Height)	Dry Wt.(g)	Subm. Wt. (g)	SSD Wt.(g)	Gmb	Stability	Max. Load (KN)	ITS (Kpa)
Unconditioned (Dry)	50% DCWA	A	70.00	1,248.30	682.60	1,253.00	2.19	26.29	5.19	0.46
		B	71.20	1,247.60	687.20	1,253.60	2.20	27.10	5.50	0.48
		Average	70.60	1,247.95	684.90	1,253.30	2.20	26.70	5.35	0.47
Conditioned (Wet)	50% DCWA	C	69.50	1,240.50	680.50	1,248.30	2.18	19.37	3.82	0.35
		D	70.10	1,241.20	681.50	1,248.80	2.19	20.12	3.79	0.36
		Average	69.80	1,240.85	681.00	1,248.55	2.19	19.75	3.81	0.35
Tensile Strength Ratio (TSR)=(Wet /Dry), %										74%

Table 4.13 Indirect Tensile Strength (ITS) test result 50% DCWA

Indirect Tensile Strength(ITS) and Tensile Strength Ration (TSR) For 50 % DCWA										
Sample	DCWA %	Sample No	Spec. (Height)	Dry Wt.(g)	Subm. Wt.(g)	SSD Wt.(g)	Gmb	Stability	Max. Load (KN)	ITS (KPA)
Unconditioned (Dry)	25% DCWA	A	72.50	1,244.20	670.40	1,250.70	2.14	27.12	5.35	0.46
		B	72.30	1,244.30	670.50	1,251.30	2.14	27.40	5.23	0.46
		Average	**72.40**	**1,244.25**	**670.45**	**1,251.00**	**2.14**	**27.26**	**5.29**	**0.46**
Conditioned (Wet)	25% DCWA	C	72.00	1,250.00	674.50	1,255.60	2.15	20.68	4.08	0.36
		D	71.80	1,251.00	675.30	1,256.70	2.15	20.35	4.06	0.36
		Average	**71.90**	**1,250.50**	**674.90**	**1,256.15**	**2.15**	**20.52**	**4.07**	**0.36**
Tensile Strength Ratio (TSR)=(Wet /Dry), %										**78%**

Table 4.14 Indirect Tensile Strength (ITS) test result for 25% DCWA

The volumetric, stability and flow values for the different composition of the aggregate revealed that incorporating demolished concrete waste aggregate up to 25% fulfill every marshal mix criteria whereas at 50% and 75% DCWA the flow value is beyond the specification and for 75% DCWA stability and VFA were out of the specification. Accommodation of this value to some extent will be possible based on the project specific attributes. The grade of bitumen will also influence this characteristic. The other observation is the bitumen content. The bitumen content increases when the portion of demolished concrete waste aggregate increases. The indirect tensile strength result shows better value for lower demolished concrete waste aggregate incorporation. Both at 25% DCWA and 50% DCWA the indirect tensile strength ratio exceeds the specification limit which is >**79%** without any treatment. Even though this is the fact to moisture induced damage due to absorptive properties of recycled aggregate some measures could be taken to incorporate the recycled aggregate. Among those curing of the mixtures in oven for some hours is one of the methods investigated by (A.R.Pasandín & Pérez, 2014).

CHAPTER – 5

RECOMMENDATION AND CONCLUTION

5.1. Conclusion

Laboratory tests were conducted to evaluate the physical properties of demolished concrete waste aggregate collected from demolished site of Jimma University main campus and crushed to appropriate size with aggregate crusher. Different tests were conducted and the results are evaluated with corresponding ERA specifications of a coarse aggregate material for hot mix asphalt.

The study also investigated volumetric properties of hot mix asphalt prepared by Marshall Mix design method where the constituents were demolished concrete waste aggregate and natural crushed aggregate. Based on the mix design optimum asphalt content was determined for four different percentage composition of demolished concrete waste aggregate (DCWA) in hot mix asphalt. Additionally moisture induced damage was evaluated in laboratory for 25% and 50% compositions of demolished concrete waste aggregate at the respective optimum bitumen contents.

Summarizes the overall findings achieved through the laboratory results to achieve the objectives of the research as follows: - One of the objectives was to evaluate the physical properties of demolished concrete waste aggregate and compare the properties with natural crushed aggregate and evaluate in terms of ERA specification for hot mix asphalt. Accordingly the test results revealed that demolished concrete waste aggregate has lower specific gravity and higher water absorption which is resulted from porous attached mortar on the DCWA. These attributes significantly affect the strength and durability characteristics of demolished concrete waste aggregates makes less durable, less strong and more moisture susceptible than natural aggregates.

The other objective was to determine the optimum bitumen content for different proportions of DCWA replacement through the process of optimum bitumen content determination, the volumetric properties of the paving mixture prepared by Marshall Mix design method was assessed and observed that the air voids in demolished concrete aggregate is higher and above expected (4%) even at higher bitumen content. The cause for this was the breaking of the attached mortar through Marshall Compaction of 75*2 blows which was create uncoated surface and more void in the mix.

It was investigated if the cause for this higher void was stem from the calculation of the maximum theoretical density. But the maximum theoretical density determination from laboratory prepared loose specimen has no significant difference from maximum theoretical density determined from compacted specimen. Optimum bitumen content increases when the percentage of demolished concrete waste aggregate increases. The bitumen content ranges from 5.5%- 7.5% by weight when the demolished concrete waste aggregate percentage increases from 25%- 75% whereas the optimum bitumen content for natural aggregate is 4.8%. The possible cause for this attribute was the absorptive property of the mortar on the demolished concrete waste aggregate.

50% & 75% demolished concrete waste aggregate does not fulfill the ERA and MS-2 criteria of flow range from 2-4 and 75% DCWA also does not fulfill the ERA and MS-2 requirement of stability and VFA range. This was the limitation to replace natural aggregate to these proportions unless otherwise considerations are taken to accommodate to a certain deviation value for specific projects. The stability of hot mix asphalt with demolished concrete waste aggregate increases as the percentage of incorporated demolished concrete waste aggregate increases but at 75% DCWA the case does not applied. The stability of mixture with natural aggregate is less than the stability of the paving mix with DCWA. The test result revealed that moisture induced damage increases as the percentage of demolished concrete waste aggregate increases.

The ITS test conducted to assess moisture susceptibility of paving mixture revealed that the tensile strength ratio of conditioned specimen to dry specimens gives satisfactory result when evaluated according to ERA specification up to 75% replacement of demolished concrete waste aggregate with natural crushed aggregate. The main reason for this deduction is that of the economic advantage. Since bitumen is imported with foreign currency and aggregates are found in abundance in the country, utilizing demolished concrete waste aggregate in hot mix asphalt will have economic disadvantage in pavement construction. Therefore further researches and treatments are required to replace demolished concrete waste aggregate to some extent of natural aggregate in hot mix asphalt.

5.2. Recommendations

The study was carried out using particular demolished concrete waste aggregate hence, extensive laboratory experimental results should be addressed in considering practical applications of a wider range of these demolished concrete waste materials. Since the performance and the properties of demolished concrete waste aggregate in hot mix asphalt is largely depending on the nature of virgin aggregate, the nature and origin of demolished concrete waste aggregate, the treatment used to improve the demolished concrete waste aggregate properties and the type of mineral filler used.

Immense works are remaining regarding to recycling of aggregates for road construction purpose. Demolished concrete waste aggregate can be considered as aggregate material for hot mix asphalt up to 50% by weight incorporation with natural crushed aggregate and also can be considered as other types of applications like as unbounded base course, sub base, filler material in hot mix asphalt. and for others with extensive researches and giving concern by the respective authorities for recycling of demolition concrete wastes to preserve the natural resources(virgin aggregates) and to preserve landfills.

Recycling of demolition concrete wastes aggregate shall not be considered only from point of view of direct monetary savings, but also from environmental protection, landfill conservation, energy savings and other mutual savings. Life cycle cost analysis can be conducted for the entire feasibility of recycling of demolition wastes.

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APPENDEXS

APPENDEX –A Test Result for Physical property of aggregates (DCWA & NCA)

Table A1: Physical property test for demolished concrete waste aggregate

Specific Gravity and Water Absorption of DCW Coarse Aggregate				
Trial	**1**	**2**	**Average**	**Specification**
Weight of Sample ,g	2000	1998	1999	
Weight of Vessel +Sample +Water ,g	1684.1	1678.3	1681.2	
Weight of Vessel +Water ,g	456	456	456	
A. Weight of SSD Sample in Air (C) ,g	2096.4	2098.4	2097.4	
B. Mass of Saturated Sample in Water (gm)	1228.1	1222.3	1225.2	
C. Weight of Oven Dry Sample (D) ,g	1913.38	1925.48	1919.43	
Bulk Sp. gravity (SSD) = A/(A-B)	**2.414372913**	**2.39516037**	**2.40**	
Bulk Sp. gravity (Oven dry) = C/(A-B)	**2.203593228**	**2.19778564**	**2.20**	
Apparent Specific gravity = C/(C-B)	**2.792**	**2.738**	**2.77**	
Water Absorption (%) w = (A-C)*100/C	**9.565**	**8.981**	**9.27**	**> 2**
Sr > Ss > Sd………….. Not OK!!!				

Table A2: Physical property test for demolished concrete waste aggregate

Aggregate Crushing Value (ACV) Test for Demolished Concrete				
Trial	**1**	**2**	**Average**	**Specification**
Mass of aggregate before test passing 12.5 mm and retain on 10mm sieves M_1(g)	2060.3	2078.5	2069.4	
Mass of aggregate after compression Retained on 2.36mm sieve, M_2(g)	615.2	617.4	616.3	
ACV (%) = (M_2/M_1) * 100	**29.86**	**29.70**	**29.78**	
Average ACV (%)	**29.78**			
Specification (%)	**< 25**			

Table A3: Physical property test for demolished concrete waste aggregate

Aggregate Impact Value (AIV)				
Trial	**1**	**2**	**Average**	**Specification**
Mass of aggregate before test passing 12.5mm and retain on10mm sieves M_1(g)	476	489	482.5	
Mass of aggregate after impact load Passing 2.36mm sieve, M2 (g)	119.5	120.3	119.9	
Mass of aggregate after impact load Retained on 2.36mm sieve, M3(g M1-M2	356.5	368.7	362.6	
ACV (%) = (M_2/M_1) * 100	**25.1**	**24.6**	**24.9**	
Average ACV (%)	**24.9**			
Specification (%)	**< 25**			

Table A4: Physical property test for demolished concrete waste aggregate

Los Angles Aeration Value (LAAV) ASTM C131-98				
Trial	**1**	**2**	**Average**	**Specification**
Grading Used	A	A		
Mass of sample before test, M1 (gm)	5000	5000	5000.0	
Mass Passing Sieve Size 1.7mm,M2 (gm)	909.6	910.7	910.2	
Mass retained on Sieve Size 1.7mm, M3 M1-M2(gm)	4090.4	4089.3	4089.9	
LAA (%) = (M2/M1)*100	**18.2**	**18.2**	**18.2**	
Average LAA (%)	**18.2**			
Specification	**< 25**			

Table A5: Physical property test for natural crushed aggregate (NCA)

Specific Gravity and Water Absorption of Course Aggregate for natural crushed aggregate (NCA) (AASHTO T85 - 91)

Material Type :-	Wearing Course	Date Sampled :-	29-Aug-20
Source :-	Natry Crusher	Date Tested :-	30-Aug-20
Lab	Jimma University Institut of Technology	Tested by :-	Kinfe.G

TEST DATA

Coarse aggregate

Description	1	2	Average
A. Mass of Oven Dry Sample in air gm	2348.5	2309.5	2329.000
B. Mass of Saturated Surface Dry in Air, SSD, gm	2388	2350.5	2369.250
C. Mass of Sample in Water gm	1516.3	1490	1503.150
Absorption of water (B - A)*100/A	1.682	1.775	1.729
Temperature , °C	23±1.7	23±1.8	
Apparent Specific gravity, A/(A-C)	2.822	2.818	2.820
Bulk specific gravity, A/(B-C)	2.694	2.684	2.689
Bulk specific gravity, SSD basis B/(B-C)	2.739	2.732	2.736

Table A6: Physical property test for natural crushed aggregate (NCA)

Specific Gravity and Water Absorption of Course Aggregate for natural crushed aggregate (NCA) (AASHTO T85 - 91)

Material Type :-	Wearing Course	Date Sampled :-	29-Sep-20
Source :-	Natry Crusher	Date Tested :-	30-Oct-20
Lab Station at :-	Jimma University Institute of Technology	Tested by :-	Kinfe.G

TEST DATA

Fine aggregate

Description	1	2	Average
A. Mass of Oven Dry Sample in air gm.	492.3	491.3	
B. Mass of Saturated Surface Dry in Air gm.	506.2	500.5	
C. Mass of Flask + Water gm.	730.7	732.7	
D. Mass of Flask + Water +Sample gm.	1046	1042.6	
Absorption of water (B - A)*100/A	1.100	1.010	1.055
Temperature , °C	23±1.7	23±1.7	
Apparent Specific gravity, A/(A-(D-C))	2.781	2.708	2.745
Bulk specific gravity, A/(B-(D-C))	2.579	2.578	2.578
Bulk specific gravity, SSD basis B/(B-(D-C))	2.652	2.626	2.639

Table A7: Physical property test for natural crushed aggregate (NCA)

Trail :- 1

Los Angles Abrasion Test result for natural crushed aggregate (NCA) (AASHTO T-96)

Sieve Size		Weight of indicated sizes, g			
Passing	Retained	A	B	C	D
37.5 mm	25.0 mm	1250±25	……….	………..	………..
25.0 mm	19.0 mm	1250±25	……….	………..	………..
19.0 mm	12.5 mm	1250±10	2500±10	………..	………..
12.5 mm	9.5 mm	1250±10	2500±10	……….	………..
9.5 mm	6.3 mm	……….	……….	2500±10	………..
6.3 mm	4.75 mm	………	……..	2500±10	………..
4.75 mm	2.36 mm	………	……….	………..	5000±10
Total		5000±10	5000±10	5000±10	5000±10
No. of spheres		12	11	8	6
Mass of Charge, gm		5000±25			

Sieve Size		Weight of Sample before test ,gm	Weight of Retained on SieveNo.12 ,gm	Weight of passing SieveNo.12 ,gm	Percent Loss %
Passing	Retained				
37.5 mm	25.0 mm				
25.0 mm	19.0 mm				
19.0 mm	12.5 mm	2500.3			
12.5 mm	9.5 mm	2500.4			
9.5 mm	6.3 mm				
6.3 mm	4.75 mm				
4.75 mm	2.36 mm				
Total		5000.7	4378.1	622.6	12.5%

Table A8: Physical property test for natural crushed aggregate (NCA)

Trail :- 2

Los Angles Abrasion Test result for natural crushed aggregate (NCA) (AASHTO T-96)

Sieve Size		Weight of indicated sizes, g			
Passing	Retained	A	B	C	D
37.5 mm	25.0 mm	1250±25	……….	………..	………..
25.0 mm	19.0 mm	1250±25	……….	………..	………..
19.0 mm	12.5 mm	1250±10	2500±10	………..	………..
12.5 mm	9.5 mm	1250±10	2500±10	……….	………..
9.5 mm	6.3 mm	……….	……….	2500±10	………..
6.3 mm	4.75 mm	………	……..	2500±10	………..
4.75 mm	2.36 mm	………	……….	………..	5000±10
Total		5000±10	5000±10	5000±10	5000±10
No. of spheres		12	11	8	6
Mass of Charge, gm		5000±25			
Sieve Size		Weight of Sample before test ,gm	Weight of Retained on SieveNo.12 ,gm	Weight of passing SieveNo.12 ,gm	Percent Loss %
Passing	Retained				
37.5 mm	25.0 mm				
25.0 mm	19.0 mm				
19.0 mm	12.5 mm	2500.1			
12.5 mm	9.5 mm	2500.3			
9.5 mm	6.3 mm				
6.3 mm	4.75 mm				
4.75 mm	2.36 mm				
Total		5000.4	4372.8	627.6	12.6%

Table A9: Physical property test for natural crushed aggregate (NCA

Material Type:-	Wearing Course	Date Sampled:-	29-Sep-20
Soruce :-	Natry Crusher	Date Tested:-	3-Oct-20
Lab Location :-	Jimma University Institut of Technology	Tested by :-	Kinfe.G

Aggregate Crushing Value (Acv) for (NCA) BS 812 Part 110 : 1990

SAMPLE NO.	1	2
Size of aggregates ,mm	10 - 14	10 _14
Maximum load applied ,KN	400	400
Duration of testing ,mm	10	10
Weight of sample tested ,gm	2636.1	2693.6
Wt. of sample rets. On 2.36 sieve ,gm	2117.7	2170.7
Aggregate crushing Value ,%	19.7	19.4
Average aggregate. crushing value,%	19.5	

Table A10: Physical property test for natural crushed aggregate (NCA

Material Type:-	Wearing Course	_	Date Sampled:-	29-Sep-20
Source :-	Natry Crusher		Date Tested:-	3-Oct-20
Lab Location :-	JIT Lab		Tested by :-	Kinfe.G

Ten Percent Fines Value (%FACT VALUE) BS 812 Part 110 : 1990

Material Condition	Dry		Wet	
Sample No.	1	2	1	2
Size of aggregates ,mm	10 14	10 14	10 14	10 14
Load achieved at required Penetration of Plunger (f) ,KN	307.7	317.4	307.7	317.4
Duration of testing ,mm	10 ±30Sec.	10 ±30Sec.	10 ±30Sec.	10 ±30Sec.
Penetration of Plunger ,mm	20	20	20	20
Weight of sample tested ,gm	2627.0	2622.4	2660.8	2682.2
Wt. of sample ret. On 2.36 sieve ,gm	2354.4	2369.6	2365.3	2374.3
%of material passing 2.36 mm	10.4	9.6	11.1	11.5
Force required to produce 10% fine (TFV)in KN	299.6	325.8	285.2	287.1
Average Force TFV in KN	312.7		286.1	
Wet / Dry relationship,%	91.5			

Remark:- F=14Xf/(m+4)

Percent of Plunger

15mm rounded or partially rounded aggregates

20mm for normal crushed aggregates

24mmfor vesicular (honeycombed)aggregates

APPENDEX –B Particle size distribution of both aggregate (DCWA & NCA)

Table B1: Particle size distribution for natural aggregate (NCA)

Aggregate Gradation for Natural Aggregate Percentage by Pass						
Sieve Size (mm)	Weight Retained (gm.)	% Retained	Cumulative %Retain	% Pass	ASTM 3515D Specification	
					LL	UL
25	**0**	0	0	100	100	100
19	**69.6**	5.8	5.8	94.2	90	100
12.5	**198**	16.5	22.3	77.7	71	88
9.5	**118.8**	9.9	32.2	67.8	56	80
4.75	**246**	20.5	52.7	47.3	35	65
2.36	**171.6**	14.3	67	33	23	49
1.18	**126**	10.5	77.5	22.5	15	37
0.6	**91.2**	7.6	85.1	14.9	10	28
0.3	**62.4**	5.2	90.3	9.7	5	19
0.15	**28.8**	2.4	92.7	7.3	4	13
0.075	**21.6**	1.8	94.5	5.5	2	8
Pan	**66**	5.5	100	0		
Total	**1200**	**100**				
Wight of Bitumen (g)						

Table B2: Particle size distribution for demolished concrete waste aggregate (DCWA)

Sieve Size (mm)	Aggregate Gradation for DCWA Percentage by Pass							ASTM 3515D Specification	
	Weight Retained (gm.)	25% DCWA	50% DCWA	75% DCWA	% Retained	Cumulative %Retain	% Pass	LL	UL
25	0	0	0	0	0	0	100	100	100
19	69.6	17.4	34.8	52.2	5.8	5.8	94.2	90	100
12.5	198	49.5	99	148.5	16.5	22.3	77.7	71	88
9.5	118.8	29.7	59.4	89.1	9.9	32.2	67.8	56	80
4.75	246	61.5	123	184.5	20.5	52.7	47.3	35	65
2.36	171.6				14.3	67	33	23	49
1.18	126				10.5	77.5	22.5	15	37
0.6	91.2				7.6	85.1	14.9	10	28
0.3	62.4				5.2	90.3	9.7	5	19
0.15	28.8				2.4	92.7	7.3	4	13
0.075	21.6				1.8	94.5	5.5	2	8
Pan	66				5.5	100	0		
Total	1200				100				

APPENDEX –C Bitumen Quality Test Result

Table C1: Bitumen quality test result

Trial No	AASHTO T 44 Solubility in Trichloro ethylene,(%)	AASHTO T 48 Flash Point, ºC	AASHTOT49 Penetration at 25ºC, 100g, 5sec	ASHTOT 51 Ductility at 25ºC (cm)	AASHTO T 53 Softening Point (0C)	AASHTO T228-06 Specific gravity at 25ºC (kg/m3)
1	99.10	288.00	66.00	147.00	53.00	1.08
2	99.20	298.00	64.00	154.00	55.00	1.10
Average	**99.15**	**293.00**	**65.00**	**150.50**	**54.00**	**1.09**
Standard Specification	>99	>219	60-70	>75	42-51	NA

APPENDEX –D Test Result for Marshal Mix Design

Table D1: Marshall Test Results Prepared by 0 % demolished concrete waste aggregate

MARSHALL PROPERTIES OF BITUMINOUS MIXTURES ASTM D 1559 - AASHTO T 245				
GENERAL DATA	Size mm	%	Bulk	Apparent
Tested by: - Kinfe. G/Georges	A.24-18mm	29%	2.637	2.705
Purpose -Final Thesis	B.18-13mm	27%	2.657	2.704
Source:-ERA ASENDABO STOCK	C.13-5mm	14%	2.653	2.703
Grade :-60/70	D.5-0mm	29%	2.620	2.718
Bitumen S.G (Gb) =1.08	F. Crushed filler	5.50%		
Marshal compaction =2*75 blow			2.615	2.750
% of Demolished Concrete waste Aggregate =0%	GSB =2.2		GSA =	2.606

Marshall Properties of Asphalt mix with 5.5% filler for different bitumen content Control Mix (0%DCW &100%NCA)

BC (%)	Sample No	Spec. Height (cm)	Dry Wt. (g)	Subm. Wt.(g)	SSD Wt. (g)	Gmb	Gmm	VTM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)	Peak .Load
A	B	C	D	E	F	G	H	J	K	L	M	N	O
4.0	A	66.50	1,248.50	682.50	1,256.30	2.18	2.44	10.84	20.06	45.98	8.00	3.24	10.01
	B	67.00	1,247.70	685.50	1,259.60	2.17	2.41	9.97	20.15	50.51	8.50	3.50	9.82
	Average	66.75	1,248.10	684.00	1,257.95	2.17	2.43	10.41	20.11	48.25	8.25	3.37	9.92
4.5	A	67.00	1,247.30	693.20	1,250.10	2.24	2.40	6.56	18.14	63.82	9.80	3.24	10.01
	B	63.00	1,249.30	691.50	1,250.30	2.24	2.38	6.06	18.29	66.85	9.30	3.50	9.82
	Average	65.00	1,248.30	692.35	1,250.20	2.24	2.39	6.31	18.22	65.33	9.55	3.37	9.92
5.0	A	68.50	1,248.60	697.60	1,255.30	2.24	2.36	5.13	18.60	72.40	9.50	3.60	9.99
	B	69.25	1,249.98	699.70	1,254.90	2.25	2.37	4.87	18.15	73.16	9.30	3.40	9.70
	Average	68.88	1,249.29	698.65	1,255.10	2.25	2.36	5.00	18.37	72.78	9.40	3.50	9.85
5.5	A	69.50	1,249.20	698.80	1,252.05	2.26	2.36	4.33	18.34	76.37	8.50	3.21	9.44
	B	69.25	1,248.35	698.45	1,253.40	2.25	2.38	5.55	18.65	70.22	8.50	3.85	10.32
	Average	69.38	1,248.78	698.63	1,252.73	2.25	2.37	4.94	18.49	73.29	8.50	3.53	9.88
6.0	A	69.50	1,253.60	698.30	1,254.40	2.25	2.36	4.63	18.90	75.53	9.56	4.210	12.02
	B	69.25	1,253.35	699.20	1,252.55	2.27	2.38	4.80	18.52	74.10	3.77	3.770	11.05
	Average	69.38	1,253.48	698.75	1,253.48	2.26	2.37	4.71	18.71	74.82	6.67	3.99	11.54

Table D2: Marshall Test Results Prepared by 25 % demolished concrete waste aggregate

MARSHALL PROPERTIES OF BITUMINOUS MIXTURES ASTM D 1559 - AASHTO T 245

GENERAL DATA	Size mm	%	Bulk	Apparent
Tested by:- Kinfe. G/Georges	A.24-18mm	29%	2.637	2.705
Purpose -Final Thesis	B.18-13mm	27%	2.657	2.704
Source:-ERA ASENDABO STOCK	C.13-5mm	14%	2.653	2.703
Grade :-60/70	D.5-0mm	29%	2.620	2.718
Bitumen S.G (GB) =1.08	F. filler	5.50%		
Marshal compaction =2*75 blow		2.615		2.750
% of Demolished Concrete waste Aggregate =50%	Gsb =2.2		Gsa =	2.606

Marshall Properties of Asphalt mix with 5.5% filler for different bitumen content 25%DCW & 75%NCA Replacement

BC (%)	Sample No	Spec. Height (cm)	Dry Wt. (g)	Subm.Wt.(g)	SSD Wt. (g)	Gmb	Gmm	VTM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)	Peak .Load
A	B	C	D	E	F	G	H	J	K	L	M	N	O
4.50	A	71.30	1,245.70	683.56	1,257.60	2.17	2.44	10.14	20.69	50.98	9.77	2.98	9.99
	B	71.50	1,243.20	684.80	1,256.60	2.17	2.39	9.97	20.54	51.45	8.78	3.60	9.70
	Average	**71.40**	**1,244.45**	**684.18**	**1,257.10**	**2.17**	**2.42**	**10.06**	**20.61**	**51.21**	**9.28**	**3.29**	**9.85**
5.00	A	72.50	1,249.50	689.80	1,250.60	2.23	2.44	7.74	18.59	58.36	8.77	3.08	9.99
	B	71.80	1,249.90	686.40	1,250.21	2.22	2.39	8.20	19.00	56.82	8.35	3.60	9.70
	Average	**72.15**	**1,249.70**	**688.10**	**1,250.41**	**2.22**	**2.42**	**7.97**	**18.79**	**57.59**	**8.56**	**3.34**	**9.85**
5.50	A	72.00	1,248.90	698.90	1,250.60	2.26	2.38	5.02	18.13	72.29	8.66	2.99	9.99
	B	73.00	1,249.80	699.70	1,251.50	2.26	2.39	4.97	18.09	72.50	8.19	3.70	9.70
	Average	**72.50**	**1,249.35**	**699.30**	**1,251.05**	**2.26**	**2.38**	**5.00**	**18.11**	**72.39**	**8.43**	**3.35**	**9.85**
6.00	A	71.00	1,248.20	699.00	1,251.00	2.26	2.36	4.19	18.65	77.57	8.89	3.50	9.44
	B	71.00	1,249.30	698.10	1,251.50	2.26	2.37	4.75	18.79	74.74	8.56	3.60	10.32
	Average	**71.00**	**1,248.75**	**698.55**	**1,251.25**	**2.26**	**2.37**	**4.47**	**18.72**	**76.15**	**8.73**	**3.55**	**9.88**
6.50	A	70.00	1,249.50	698.80	1,250.80	2.26	2.34	4.29	19.00	77.43	10.35	4.600	12.02
	B	70.00	1,248.90	699.70	1,251.20	2.26	2.39	4.25	18.97	77.61	8.07	3.100	11.05
	Average	**70.00**	**1,249.20**	**699.25**	**1,251.00**	**2.26**	**2.37**	**4.27**	**18.99**	**68.90**	**9.21**	**3.85**	**11.54**

Table D3: Marshall Test Results Prepared by 50 % demolished concrete waste aggregate

MARSHALL PROPERTIES OF BITUMINOUS MIXTURES ASTM D 1559 - AASHTO T 245

GENERAL DATA	Size mm	%	Bulk	Apparent
Tested by:- Kinfe G/Georges	A.24-18mm	29%	2.637	2.705
Purpose -Final Thesis	B.18-13mm	27%	2.657	2.704
Source:-ERA ASENDABO STOCK	C.13-5mm	14%	2.653	2.703
Grade :-60/70	D.5-0mm	29%	2.620	2.718
Bitumen S.G (Gb) =1.08	F. filler	5.50%		
Marshal compaction =2*75 blow		2.615		2.750
% of Demolished Concrete waste Aggregate =50%	Gsb =2.2		Gsa =	2.606

Marshall Properties of Asphalt mix with 5.5% filler for different bitumen content 50%DCW & 50%NCA Replacement

BC (%)	Sample No	Spec. Height (cm)	Dry Wt. (g)	Subm.Wt.(g)	SSD Wt. (g)	Gmb	Gmm	VTM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)	Peak .Load
A	B	C	D	E	F	G	H	J	K	L	M	N	O
5.00	A	73.10	1,242.69	663.80	1,268.50	2.06	2.36	12.92	25.29	48.90	9.86	4.35	9.99
	B	72.00	1,244.30	665.50	1,269.90	2.06	2.39	13.86	25.15	44.89	10.86	4.30	9.70
	Average	**72.55**	**1,243.50**	**664.65**	**1,269.20**	**2.06**	**2.38**	**13.39**	**25.22**	**46.89**	**10.36**	**4.33**	**9.85**
5.50	A	72.50	1,249.00	684.60	1,262.50	2.16	2.39	9.57	21.84	56.17	10.56	4.25	9.99
	B	74.00	1,247.80	682.80	1,260.30	2.16	2.39	9.59	21.86	56.11	9.86	4.30	9.70
	Average	**73.25**	**1,248.40**	**683.70**	**1,261.40**	**2.16**	**2.39**	**9.58**	**21.85**	**55.60**	**10.21**	**4.28**	**9.85**
6.00	A	67.50	1,238.00	686.60	1,252.50	2.19	2.38	8.08	21.30	62.06	10.30	4.70	9.99
	B	74.00	1,235.80	687.70	1,254.70	2.18	2.36	7.53	21.59	65.13	9.46	4.21	9.70
	Average	**70.75**	**1,236.90**	**687.15**	**1,253.60**	**2.18**	**2.37**	**7.81**	**21.45**	**62.06**	**9.88**	**4.46**	**9.85**
6.50	A	73.50	1,245.60	687.00	1,251.40	2.21	2.38	7.27	21.03	65.42	9.95	5.36	9.44
	B	73.00	1,241.30	684.60	1,250.60	2.19	2.37	7.46	21.52	65.32	8.44	4.52	10.32
	Average	**73.25**	**1,243.45**	**685.80**	**1,251.00**	**2.20**	**2.38**	**7.37**	**21.28**	**65.37**	**9.20**	**4.94**	**9.88**
7.00	A	72.50	1,244.20	689.60	1,254.50	2.20	2.35	6.28	21.61	70.96	8.95	4.340	12.02
	B	73.50	1,247.10	698.90	1,252.50	2.25	2.34	3.73	19.82	81.18	8.63	4.860	11.05
	Average	**73.00**	**1,245.65**	**694.25**	**1,253.50**	**2.23**	**2.35**	**5.00**	**20.72**	**76.07**	**8.79**	**4.60**	**11.54**

Table D4: Marshall Test Results Prepared by 75 % demolished concrete waste aggregate

MARSHALL PROPERTIES OF BITUMINOUS MIXTURES ASTM D 1559 - AASHTO T 245

GENERAL DATA	Size mm	%	Bulk	Apparent
Tested by:- Kinfe G/Georges	A.24-18mm	29%	2.637	2.705
Purpose -Final Thesis	B.18-13mm	27%	2.657	2.704
Source:-ERA ASENDABO STOCK	C.13-5mm	14%	2.653	2.703
Grade :-60/70	D.5-0mm	29%	2.620	2.718
Bitumen S.G (Gb) =1.08	F. filler	5.50%		
Marshal compaction =2*75 blow		2.615		2.750
% of Demolished Concrete waste Aggregate =75%	Gsb =2.2		Gsa =	2.606

Marshall Properties of Asphalt mix with 5.5% filler for different bitumen content 75%DCW & 25%NCA Replacement

BC (%)	Sample No	Spec. Height (cm)	Dry Wt. (g)	Subm. Wt.(g)	SSD Wt. (g)	Gmb	Gmm	VTM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)	Peak .Load
A	B	C	D	E	F	G	H	J	K	L	M	N	O
5.50	A	78.50	1,232.10	643.50	1,259.60	2.00	2.38	15.80	27.68	42.92	7.90	4.55	10.20
	B	77.80	1,230.10	642.60	1,258.00	2.00	2.37	15.84	27.71	42.85	8.01	4.90	10.02
	Average	78.15	1,231.10	643.05	1,258.80	2.00	2.38	15.82	27.69	42.88	7.96	4.73	10.11
6.00	A	77.50	1,232.10	658.50	1,252.80	2.07	2.38	13.07	25.42	48.57	8.20	4.60	10.20
	B	76.80	1,230.80	656.60	1,253.40	2.06	2.39	13.53	25.81	47.58	7.94	5.90	10.02
	Average	77.15	1,231.45	657.55	1,253.10	2.07	2.39	13.30	25.61	48.07	8.07	5.25	10.11
6.50	A	77.00	1,239.10	652.60	1,245.50	2.09	2.36	11.29	25.22	55.21	7.72	5.01	9.99
	B	76.50	1,238.30	658.70	1,247.70	2.10	2.35	10.76	24.77	56.55	8.64	5.37	9.70
	Average	76.75	1,238.70	655.65	1,246.60	2.10	2.36	11.03	24.99	54.45	8.18	5.19	9.85
7.00	A	75.00	1,241.10	669.50	1,254.00	2.12	2.35	10.14	24.43	58.51	7.60	5.30	9.44
	B	75.00	1,248.50	669.60	1,252.50	2.14	2.38	9.35	23.77	60.66	7.30	5.10	10.32
	Average	75.00	1,244.80	669.55	1,253.25	2.13	2.36	9.74	24.10	59.58	7.45	5.20	9.88
7.50	A	73.50	1,236.50	688.70	1,248.10	2.21	2.32	4.81	21.75	77.91	7.21	5.800	12.02
	B	74.00	1,239.70	684.10	1,247.20	2.20	2.32	5.19	22.06	76.49	6.50	5.900	11.05
	Average	73.75	1,238.10	686.40	1,247.65	2.21	2.32	5.00	21.91	77.20	6.86	5.85	11.54

Table D5: Theoretical Maximum Specific Gravity (GMM) for **0% DCWA**

GMM For Natural Crushed Aggregate (NCA)										
Filler Content	5.5%	6.5%	5.5%	6.5%	5.5%	6.5%	5.5%	6.5%	5.5%	6.5%
Bitumen Content	4.0%		4.5%		5.0%		5.5%		6.0%	
Trial Name	A	B	A	B	A	B	A	B	A	B
A. Mass of Dry Sample in Air	1,248.20	1,256.30	1,249.60	1,255.20	1,244.70	1,254.10	1,260.60	1,254.70	1,265.00	1,257.60
B. Mass of Jar Filled With Water	3,533.90	3,533.90	3,533.90	3,533.90	3,533.90	3,533.90	3,533.90	3,533.90	3,533.90	3,533.90
C. Mass of Jar Filled With Water + Sample	4,270.60	4,269.80	4,262.20	4,261.70	4,259.60	4,258.10	4,260.40	4,261.80	4,263.70	4,263.30
Maximum Theoretical Specific Gravity = K*A/(A+B-C)	2.440	2.414	2.397	2.380	2.398	2.367	2.360	2.382	2.364	2.381
Average Maximum Theoretical Specific Gravity(Gmm)	**2.43**		**2.39**		**2.38**		**2.37**		**2.37**	

Table D6: Theoretical Maximum Specific Gravity (GMM) for **25% DCWA**

GMM For 25% Demolished Waste Concrete Replacement(DCW)										
Filler Content	5.5%									
Bitumen Content	5.3%		5.3%		5.3%		5.8%		6.3%	
Trial Name	A	B	A	B	A	B	A	B	A	B
A. Mass of Dry Sample in Air	1,253.40	1,252.70	1,252.50	1,251.80	1,251.50	1,251.80	1,257.20	1,258.23	1,269.50	1,268.70
B. Mass of Jar Filled With Water	2,378.00	2,380.20	2,378.00	2,380.20	2,378.00	2,380.20	2,378.00	2,378.00	2,378.00	2,378.00
C. Mass of Jar Filled With Water + Sample	3,119.10	3,117.90	3,117.10	3,114.90	3,112.50	3,113.60	3,112.20	3,114.10	3,121.20	3,123.50
Maximum Theoretical Specific Gravity = K*A/(A+B-C)	2.447	2.432	2.440	2.421	2.421	2.415	2.404	2.410	2.412	2.425
Average Maximum Theoretical Specific Gravity(Gmm)	**2.440**		**2.430**		**2.418**		**2.407**		**2.419**	

Table D7: Theoretical Maximum Specific Gravity (GMM) for **50% DCWA**

GMM For 50% Demolished Waste Concrete Replacement(DCW)										
Bitumen Content	4.8%		4.8%		4.8%		5.3%		5.8%	
Trial Name	A	B	A	B	A	B	A	B	A	B
A. Mass of Dry Sample in Air	1,254.70	1,256.40	1,253.90	1,257.20	1,255.40	1,256.30	1,248.60	1,249.60	1,257.50	1,258.30
B. Mass of Jar Filled With Water	2,378.00	2,380.20	2,378.00	2,380.20	2,378.00	2,380.20	2,378.00	2,378.00	2,378.00	2,378.00
C. Mass of Jar Filled With Water + Sample	3,120.10	3,120.90	3,119.50	3,121.60	3,112.50	3,113.60	3,121.30	3,115.60	3,116.70	3,123.30
Maximum Theoretical Specific Gravity = K*A/(A+B-C)	2.45	2.44	2.45	2.44	2.41	2.40	2.47	2.44	2.42	2.45
Average Maximum Theoretical Specific Gravity(Gmm)	**2.44**		**2.44**		**2.41**		**2.46**		**2.44**	

Table D8: Theoretical Maximum Specific Gravity (GMM) for **75% DCWA**

GMM For 75% Demolished Waste Concrete Replacement(DCW)										
Bitumen Content	4.8%		4.8%		4.8%		5.3%		5.8%	
Trial Name	A	B	A	B	A	B	A	B	A	B
A. Mass of Dry Sample in Air	1,254.20	1,253.80	1,255.40	1,256.30	1,255.40	1,256.30	1,248.60	1,249.60	1,257.50	1,258.30
B. Mass of Jar Filled With Water	2,378.00	2,380.20	2,378.00	2,380.20	2,378.00	2,380.20	2,378.00	2,378.00	2,378.00	2,378.00
C. Mass of Jar Filled With Water + Sample	3,104.70	3,107.30	3,101.50	3,102.30	3,101.50	3,102.30	3,094.30	3,105.30	3,108.70	3,110.50
Maximum Theoretical Specific Gravity = K*A/(A+B-C)	2.38	2.38	2.36	2.35	2.36	2.35	2.35	2.39	2.39	2.39
Average Maximum Theoretical Specific Gravity(Gmm)	**2.38**		**2.36**		**2.36**		**2.37**		**2.39**	

APPENDEX –E Sample photos during laboratory and data collection


17/7/20, Captured by Kinfe.G/G
Demolished concrete waste site


17/7/20, Captured by Kinfe.G/G
Demolished concrete waste site


27/10/20, Captured by Mesganaw ayle
Sieve the aggregates by standard sieve


27/10/20, Captured by Mesganaw ayle
Sieve the aggregates by standard sieve


2/11/20, Captured by Mesganaw ayle
Quartering aggregates for test


2/11/20, Captured by Mesganaw ayle
quartering aggregates for test

28/10/20, Captured by Dejeni Dreji
Testing aggregates (ACV, AIV)

28/10/20, Captured by Dejeni Dreji
Testing aggregates (ACV, AIV)

29/10/20, Captured by Kinfe G/G
NCA for HMA preparation

29/10/20, Captured by Kinfe.G/G
DCWA for HMA preparation

05/11/20, Captured by Kinfe G/G
Aggregates in oven up to 24hr

05/11/20, Captured by Hacalu Kebed
Weighting aggregate and bitumen

05/11/20, Captured by Hachalu Kebed
Aggregates and bitumen mixing

05/11/20, Captured by Kinfe G/g
Compacting the mix 75 blows each side

06/11/20, Captured by Hachalu Kebed
Extruding spacemen after 24hr

06/11/20, Captured by Hachalu Kebed
weighting the spacemen for bulk specific gravity

27/11/20, Captured by Hachalu Kebed
Bulk specific Gravity

27/11/20, Captured by Kinfe.G/g
Spacemen in water bath for 30minutes

27/11/ 20, Captured by Dejni Dreji

Marshal test apparatus seat up

27/11/ 20, Captured by Dejni Dreji

Marshal Stability and flow test in progress

26/11/20, Captured by Dejni Dreji

Weighting los state mixture

26/11/20, Captured by Dejni Dreji

Vacuum application for saturated sample test

03/12/20, Captured by Kinfe G/georges

Conditioned and UN conditioned specimen

03/12/20, Captured by Kinfe G/georges

` ***ITS testing step***