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STUDY ON PROPERTIES OF COLD MIX ASPHALT USING INDUSTRIAL WASTES AS FINE AGGREGATES

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ABSTRACT

Cold mix asphalt (CMA) is a sustainable substitute for conventional hot mix asphalt (HMA) since it uses less energy and produces fewer greenhouse gas emissions during manufacture. This study examines the possibility of incorporating industrial waste materials as fine aggregates in CMA formulations, with the goal of improving sustainability and performance properties. The industrial wastes under consideration encompass many forms such as fly ash, slag, and quarry dust. The study examines the mechanical characteristics, longevity, and ecological effects of the created CMA mixes in contrast to conventional HMA.

The user's text is already straightforward and precise. These evaluations analyse the performance of industrial waste-based CMA in different loading and environmental circumstances to determine its applicability. The key findings indicate substantial effects, such as increased resistance to rutting, greater durability, or performance comparable to Hot Mix Asphalt (HMA). In addition, environmental assessments emphasize the decreased emission of carbon dioxide and the possibility for conserving resources by using industrial wastes in asphalt mixtures.

This study provides useful insights into the creation of sustainable asphalt materials through the optimization of industrial waste utilization. The results offer a scientific foundation for advocating environmentally conscious methods in road building and upkeep, in line with worldwide initiatives for sustainable infrastructure and efficient use of resources.

Key Words: Cold mix asphalt (CMA), Industrial wastes, Fine aggregates, Sustainable construction, Asphalt pavement, Mechanical properties, Environmental impact, Marshall Stability

1. INTRODUCTION

Asphalt pavement is a vital component of contemporary infrastructure, serving as essential road surfaces that enable global economic operations and societal connectivity. Nevertheless, the traditional process of manufacturing hot mix asphalt (HMA) is demanding in terms of resources, as it mainly depends on elevated temperatures and releases substantial amounts of greenhouse gases, hence giving rise to environmental apprehensions. Cold mix asphalt (CMA) has evolved as a sustainable solution to address these difficulties. It is known for its lower manufacturing temperatures, reduced energy usage, and ability to be applied in various weather situations.

The implementation of CMA not only supports worldwide initiatives to reduce carbon emissions in building but also presents possibilities to improve sustainability through the development of novel material compositions. Industrial by-products, including fly ash, slag, and quarry dust, are plentiful waste materials from different manufacturing processes. If not properly handled, these by-products can present difficulties in disposal and pose environmental hazards. Utilizing these industrial byproducts as small particles in CMA offers a viable solution to tackle environmental and engineering issues in the construction of asphalt pavements.

This study aims to examine the practicality and effectiveness of using industrial waste as fine aggregates in CMA mixes, with the goal of enhancing their mechanical qualities, durability, and environmental sustainability. The research methodology involves conducting a series of laboratory tests to thoroughly evaluate various aspects of the material. These tests include the Marshall Stability tests to measure the load-bearing capacity, Indirect Tensile Strength (ITS) tests to assess resistance to cracking, moisture susceptibility tests, and rutting resistance tests conducted under simulated traffic conditions. Comparing industrial waste-based CMA with traditional HMA will give us valuable information about its performance features and cost-effectiveness.

This research intends to provide empirical evidence that supports the implementation of sustainable asphalt technology in infrastructure construction by systematically analyzing these criteria.

The results are anticipated to provide valuable information for policymakers, engineers, and stakeholders in the construction sector. This will enable them to make well-informed decisions on the incorporation of industrial waste materials into asphalt manufacturing processes. The main objective of this study is to advocate for the adoption of a circular economy approach in road construction. This technique involves converting waste materials into useful resources, which in turn helps to achieve broader sustainability objectives and create more resilient infrastructure systems.

Components of CMA

CMA's primary ingredients are aggregates (coarse aggregate, fine aggregate, and fillers) and binding materials (cutback and emulsion). Water is an additional ingredient that distinguishes it from other asphalt combinations. The following section goes over the CMA's components.

Binding Materials

The two commonly used binding materials in the Cold Mix Asphalt are Emulsion and Cutback. These two are discussed in detail in the following section.

Emulsion

Emulsion is fluid like having very low consistency at room temperature, thus making it appropriate for CMA. Bitumen emulsion is a two-phase liquid in which bitumen globules remain as suspended globules in water. Thus, water acts as continuous phase in which bitumen globules are dispersed or scattered. Scattered and continuous phases are also called as internal and external phase respectively. The bitumen globules are kept stable using emulsifying agent which maybe cationic or anionic in nature. Generally, emulsion approximately consists of 60% bitumen and 40% water. When the emulsion is applied on the highway the water evaporates leaving behind bitumen globules which coalesce together and coat the aggregates, thus binding them together. The setting time of the emulsion used in the mix depends upon the grade of bitumen used. Cationic or anionic nature of emulsion is depicted by the type of emulsifying agent used in the mix. In anionic emulsions bituminous droplets carry a negative charge and positive charge is carried by cationic emulsion.

Cutback

Cutback is the other properly used binding material which is used for preparation of the cold mix. It is prepared by using solvent as dispersion phase. Cutback is classified as Rapid curing (RC), Medium curing (MC), and Slow Curing (SC) depending upon the time taken by the volatile solvent to evaporate. When used in the pavement construction volatile solvent evaporates which leaves behind bitumen which coats the aggregates.

2. LITERATURE REVIEW

Sarker, M. A. R., 2023 examines the integration of industrial byproducts, such as fly ash and slag, into cold mix asphalt (CMA) formulas. The research highlights the capacity of these materials to enhance both the mechanical characteristics and sustainability elements of CMA. The study intends to improve the load-bearing capacity and durability of asphalt pavements while minimizing environmental impact by using fly ash and slag, which are sustainable materials. Sarker's research highlights notable progress in CMA technology, advocating for environmentally friendly road construction techniques that are in line with worldwide sustainability efforts. This research provides vital insights into the efficient utilizations of industrial by-products in asphalt engineering, promoting the shift towards more sustainable infrastructure construction.

Ahmed, K., 2023: assesses the efficacy of integrating quarry dust as a fine aggregate in cold mix asphalt (CMA). The study focuses primarily on analyzing the long-lasting nature and ecological consequences related to this strategy. The research seeks to improve the mechanical qualities and durability of CMA in road building by using quarry dust, while also reducing environmental impact. Ahmed underscores the need of utilizing industrial waste to achieve sustainable infrastructure objectives, specifically emphasizing the potential of quarry dust to enhance pavement performance and decrease reliance on traditional materials. This review offers valuable insights into the practical implementation of sustainable practices in asphalt technology, which contribute to the promotion of environmentally friendly road construction and the preservation of resources.

Rahman, A., 2023: examines the possibility of incorporating industrial by-products into cold mix asphalt (CMA) and evaluates their effects on pavement performance and environmental sustainability. The study investigates the potential of utilising by-products like fly ash and slag to improve the mechanical qualities and durability of asphalt pavements. This approach aims to minimize environmental effect by adopting sustainable techniques. Rahman's research provides useful insights into waste management strategies in road construction, emphasizing the potential of using industrial by-products to meet sustainable infrastructure objectives. This study emphasizes the significance of implementing environmentally-friendly materials and methods in asphalt engineering, which aligns with worldwide initiatives for sustainable development and the preservation of resources.

Chowdhury, S., 2022, examines the use of quarry dust as a fine aggregate in cold mix asphalt (CMA) applications, specifically investigating its impact on pavement durability and environmental advantages. The study emphasizes the importance of recycling industrial waste in promoting the achievement of sustainable infrastructure development objectives. Chowdhury investigates the enhancement of pavement performance measures, such as durability and tolerance to environmental stressors, by adding quarry dust to CMA. This study highlights the significance of using industrial by-products into asphalt technology in order to promote environmentally friendly road construction methods. Chowdhury's research provides valuable insights on how to improve the sustainability of asphalt pavements by effectively using quarry dust and other industrial wastes.

Das, P., 2022, examines the mechanical characteristics of cold mix asphalt (CMA) that includes fly ash as a fine aggregate. The study concentrates on improving the ability of pavement to withstand rutting and increasing its lifespan by utilising industrial waste materials. Das demonstrates the enhancement of load-bearing capacity and durability in asphalt technology by including fly ash into CMA formulations, hence promoting sustainable practices. The study highlights the capacity of utilising industrial waste to improve the performance of asphalt while simultaneously decreasing its environmental impact. Das's research provides significant information on how to improve asphalt mixtures using fly ash, which supports the use of environmentally friendly methods in road construction and infrastructure development.

Ghosh, S., 2022, investigates the performance attributes of cold mix asphalt (CMA) that includes slag as a fine aggregate. The study assesses variables such as Marshall Stability and resistance to moisture degradation, with a particular focus on the contribution of industrial by-products in improving the long-term viability of asphalt. Ghosh demonstrates the enhancement of pavement durability and mechanical capabilities in road building by using slag into CMA formulations, hence promoting environmentally friendly techniques. The study provides vital insights into sustainable asphalt technology, showcasing the viability of utilising industrial waste to create durable and environmentally conscious infrastructure. Ghosh's research highlights the advantages of using slag in asphalt mixtures, which can enhance resource efficiency and minimize the environmental impact on pavement engineering.

Kumar, R., 2021, examines the mechanical and environmental consequences of integrating industrial byproducts, including fly ash and slag, into cold mix asphalt (CMA). The project aims to improve the longevity and eco-friendliness of pavements by utilising these waste materials. Kumar emphasizes the enhancements in mechanical qualities, including rutting resistance and Marshall Stability, while underscoring the significance of recycling industrial waste in the field of asphalt engineering. The study provides vital insights into the practicality of using fly ash and slag in CMA formulations to achieve environmentally friendly road construction methods. Kumar's research highlights the advantages of using waste materials to improve the performance of pavements and minimize their negative impact on the environment. This supports efforts to construct sustainable infrastructure.

Roy, A., 2021, examines the progress made in cold mix asphalt (CMA) technology, specifically in the use of quarry dust as a fine aggregate. The study assesses enhancements in pavement performance, encompassing aspects such as longevity and resilience to environmental pressures. Roy underscores the ecological advantages of utilising quarry dust in CMA, emphasizing its contribution to fostering sustainable practices in asphalt building. The research highlights the importance of integrating industrial by-products into asphalt mixtures to improve sustainability and minimize environmental harm. Roy's research provides useful insights for enhancing CMA formulations using quarry dust, which supports efforts towards sustainable infrastructure development and resource conservation in road construction.

Singh, V., 2021, examines the possibility of integrating industrial by-products into cold mix asphalt (CMA) and assesses their influence on mechanical characteristics and environmental sustainability. The study investigates the potential of industrial byproducts, such as fly ash and slag, to improve the performance of CMA in terms of Marshall Stability, resistance to rutting, and durability. Singh emphasizes the capacity of waste utilizations to decrease the environmental impact and encourage sustainable practices in road construction. The study provides valuable insights into the optimization of asphalt mixtures using industrial by-products, hence assisting progress in the creation of environmentally friendly infrastructure. Singh's research emphasizes the significance of incorporating sustainable methods into asphalt engineering, in line with worldwide efforts to decrease carbon emissions and preserve natural resources.

Das, S., 2020, investigates the mechanical characteristics of cold mix asphalt (CMA) that includes slag as a fine aggregate. The study emphasizes improvements in Marshall Stability and resilience to moisture degradation achieved by utilising industrial by-products. Das's research explores the use of slag in CMA formulations, shedding light on sustainable asphalt technologies and highlighting the importance of reusing industrial waste to improve pavement performance and longevity. The study highlights the potential advantages of using slag into asphalt mixtures to enhance mechanical characteristics and minimize ecological consequences, hence promoting sustainable approaches in road building. Das's research makes significant contributions to the progress of sustainable infrastructure development by creatively utilising industrial by-products in asphalt engineering.

Ahmed, M., in 2020, investigates the integration of fly ash into cold mix asphalt (CMA), with a focus on its impact on pavement performance and environmental sustainability. The study assesses the progress made in utilising industrial waste materials to improve the durability of asphalt and minimize its impact on the environment. Ahmed explores the enhancement of mechanical qualities, such as Marshall Stability and resilience to environmental pressures, by using fly ash into CMA formulations. The research highlights the importance of using industrial waste in asphalt engineering to promote environmentally friendly practices and support sustainable infrastructure development projects. Ahmed's research provides significant knowledge on how to improve asphalt mixtures using fly ash, emphasizing its potential to promote durable and eco-friendly road construction methods.

3. METHODOLOGY

This chapter gives brief description of materials used in sample preparation followed by the methodology used for the study.

The materials used in the experimental investigation include the following:

- Aggregates
- Coarse Aggregates
- Fine Aggregates
- Filler
- Emulsion
- Metal Shavings
- Water

Aggregates

Materials used in sample preparation were collected from Mandi. Aggregates were sieved on 13.2mm, 9.5mm, 4.75mm, 2.36mm sieves. Steel and Aluminum shavings were sieved on 2.36mm, 1.18mm and retained on 425micron sieve. The materials (coarse and fine aggregates before sieving were washed with clean water in order to remove any dust particles attached to them. After that they were oven dried at 105 °C till constant temperature was achieved. The physical properties of Aggregates according to MORTH are given below in Table 3.1.

Table 3.1 Physical Properties of Aggregates according to MORTH

Test	Specifications	Result	Specification Limit
Aggregate Impact Value	IS 2386 Part IV	19%	Max: 25%
Los Angeles Abrasion Test	IS 2386 Part IV	28%	Max: 30%
Aggregate Crushing Value	IS 2386 Part IV	23%	Max: 30%
Specific Gravity	IS: 2386-1963	2.65	2.5-3.2
Water Absorption	IS 2386 Part III	1%	1-2%
Flakiness Index	IS 2386 Part I	17%	Max: 15%

Coarse Aggregates

Coarse aggregates used for the study were collected from Mandi. The aggregates were sieved, separated and graded to agree with the gradation required for Bituminous Macadam course according to the Codal specifications and were tested as per IS: 383-1970 and 2386-1963 (I, II and III) specifications.

Fine Aggregates

Sand can be found in different zones and is usually combined in different fineness grades. Its grain can be round or angular. The fineness modulus and four zones are described in IS 383-1970. It was cleaned and well sieved so that the mortar will not affect the construction. Fine aggregate properties were evaluated as per the IS methods. River Bed Sand was the only fine aggregate used. Tests, such as crushing strength, Impact test, Soundness, Shape tests were performed on aggregates.

Filler

The Portland cement is a basic ingredient of concrete, mortar and most non-specialty grout. Portland cement is mostly used in the production of concrete. Portland cement may be grey or white. The cement properties were evaluated as per the IS: 4031-1996 and IS: 4032-1999. Pozzolanic cement is a blend of OPC i.e. PPC has a property of hydraulic setting, binding and hardening when mixed with water. Cement was the only filler used in the normal samples (NCBEM). Cement used was OPC 53 of ULTRATECH brand. Cement was sieved through 75micron sieve. The cement used was freshly prepared and was free from any inert material and did not have any lumps.

Emulsion

The emulsion used was Slow Setting Type-II emulsion, which was collected from Hindustan Colas Limited, India. Slow Setting Type-II emulsion was used as per codal specifications. Emulsion before use in the mix was properly stirred so as to have consistent mixture.

Water

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. The water is proportionate only with the cement content. It is called as the water-cement ratio. This influences the mix and thereby workability. The pH value of water should not be less than 6 and the water is free from organic matters, acids, suspended solids, alkalis and impurities.

Cold Mix Design Method

The Bituminous binders applied in cold mixes are emulsified therefore is available in liquid form. In comparison to hot mix these binders are applied at relatively colder temperature. Table3.2 shows CMA design procedure as IRC: SP:100-2014 and Table 3.3 shows design requirements for CMA Mixture as per IRC: SP:100-2014.

Table 3.2 Design Requirements for CMA Mixture as per IRC: SP: 100-2014

Properties	Values
Marshall Stability (min)	350 kg
Marshall Flow	2 mm to 8 mm
Maximum Stability Loss	50%
Level of Compaction	50 Blows on each face
Initial Emulsion Content	7% to 10%
Voids	10% to 14%

Gradation of different samples

The gradation of the coarse aggregates, quantity of the fine aggregates, cement, water and emulsion for various mixes.

Table 3.3 Gradation for Normal Samples

Sieve Size	Weight Retained (gm)
13.2mm	360
9.5mm	300
4.75mm	240
2.36mm	84
Component	**Amount**
Cement	36 gm
Water	36 ml
Fine Aggregate	180 gm
Emulsion	108 ml

Table 3.4 Gradation for 10% Steel Shavings replaced samples.

Sieve Size	Weight Retained (gm)
13.2mm	360
9.5mm	300
4.75mm	240
2.36mm	84
Component	**Amount**
Cement	36 gm
Water	36 ml
Fine Aggregate	126 gm

Emulsion	108 ml
Steel Shavings	54 gm

Categories of samples prepared

Three sets of samples were prepared during this project work on which the experimental work was carried out which are as follows:

Normal samples (NCBEM): These samples were prepared using aggregates, river bed sand, cement, water and slow setting type-II Cationic emulsion using the gradation given in table below. The aggregates used were oven dried till constant weight with surface free from any dust particles. The aggregates after grading through different sieves were washed with clean water and after that were put inside oven till constant weight was achieved.

Fine aggregates replaced with Steel shavings Samples (CBEM-S): These samples were prepared using above mentioned material. However, proportion of fine aggregates was replaced with waste steel shavings in dosages of 10%, 20%, 30%, 40% and 50%. The steel shavings used were passed through 2.36 mm sieve and were free from dust and any other particles.

Fine aggregates replaced with Aluminum shavings samples (CBEM-AL): These samples were prepared using above mentioned material. However, proportion of fine aggregate was varied and accordingly replaced by waste aluminum shavings in dosages of 10%, 20%, 30%, 40% and 50%. The shavings were checked for any dust particles and other materials.

Preparation of samples

Using above gradation NCBEM and metal replaced samples were prepared. First Coarse and Fine aggregates, Filler and Cement were mixed in dry state and then water was added to form wet mix. After that 111 ml of Emulsion was added to form sample. Then sample is kept for drying in Sun for 60 minutes such that color changes from brown to black. Then emulsified material was poured into mould (cleaned and greased) and compacted with 50 blows on either face. After that sample is kept in Oven for curing for 3 days. For the first 24 hours it is kept along with the mould.

Testing

Marshall Stability Test

In this test, the objective is to measure the resistance of a compacted cylindrical bituminous mixture specimen to plastic deformation when it is subjected to a diametrical force at a rate of 5 cm/minute. The Marshall Method of Mix Design has two primary components: the Stability-Flow Test and Density-Void Analysis.

The Marshall stability of mix is defined as the maximum load that a specimen can carry under specified standard conditions (at 60°C). The Flow value is the deformation that specimen undergoes when load reaches its highest value. The flow is expressed as deformations between the specimen's greatest loading condition and no loading circumstances, expressed in units of 0.25 mm or 0.1 mm. The apparatus consists of a cylindrical mould of height 63.5 cm and diameter 10.16 cm with collar and base plate. A compaction pedestal and a hammer of weight 4.54 Kg are used for compaction of specimen with height of fall as 45.7 cm.

Figure 3.1 Marshall Stability Test Apparatus.

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Indirect Tensile Strength:

By compressively forcing a cylindrical Marshall specimen across its vertical diametrical plane at a predetermined rate of deformation and test temperature, one can determine the indirect tensile strength of bituminous mixes. The peak load at failure is noted and utilized to determine the specimen's indirect tensile strength. According to Test Method D6927, a loading jack and ring dynamometer, a mechanical or servo-hydraulic testing device with an electronic load cell, or another device that can apply a compressive load at a controlled deformation rate while also measuring the load and deformation, meet this requirement. Concave steel loading strips with the test specimen's nominal radius as its radius of curvature.

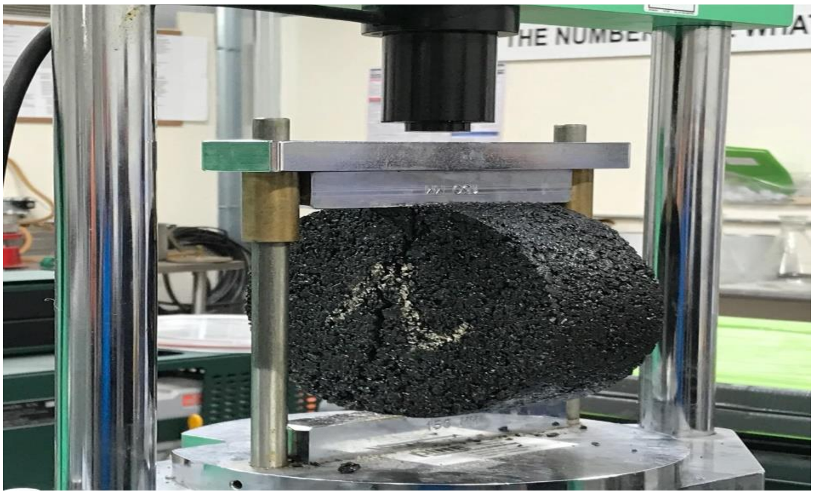

Figure 3.2 Indirect Tensile Strength Test Apparatus

4. RESULT

The physical properties of the coarse aggregates along with the maximum permissible values is shown in the Table 4.1 given below.

Table 4.1 Physical Properties of Course Aggregates as per MORTH (MORTH Specification).

Property	Recommended MORTH Specifications (maximum)	Test Results (%)
Aggregate Crushing Strength	30	17.36
Aggregate Impact Value	27	14.06
Los Angeles Abrasion Value	35	12.06
Flakiness Index	35	12.76
Elongation Index	25	17.26
Specific Gravity Value	2.5-3.2	2.63

The results of Marshall Stability test and Marshall flow value of normal samples and samples in which fine aggregates are replaced with steel and aluminum shavings at different percentages are shown in the Table 4.2 and Table 4.3 given below. Tables 4.4 and 4.5 shows Indirect Tensile Strength readings for Normal samples and samples in which fine aggregates are replaced with steel and aluminum shavings at different percentages.

Table 4.2 Marshall Stability Test Readings (Steel shavings replacing fine aggregates).

Sample	Marshall Stability (kg)	Marshall Flow (mm)
CBEM-N	455	5
CBEM-10SS	506	5.2
CBEM-20SS	660	5.3
CBEM-30SS	790	5
CBEM-40SS	710	6.5
CBEM-50SS	585	10

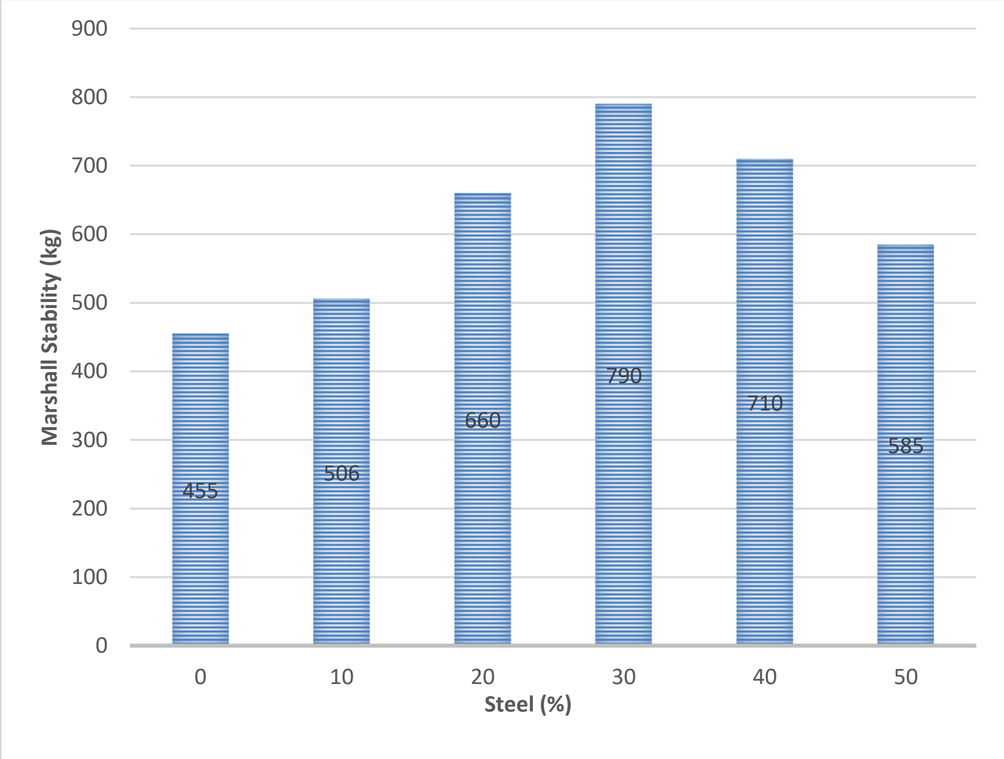

Figure 4.1 Marshall Stability (in kg) against varying Steel Shavings replacing fine aggregates.

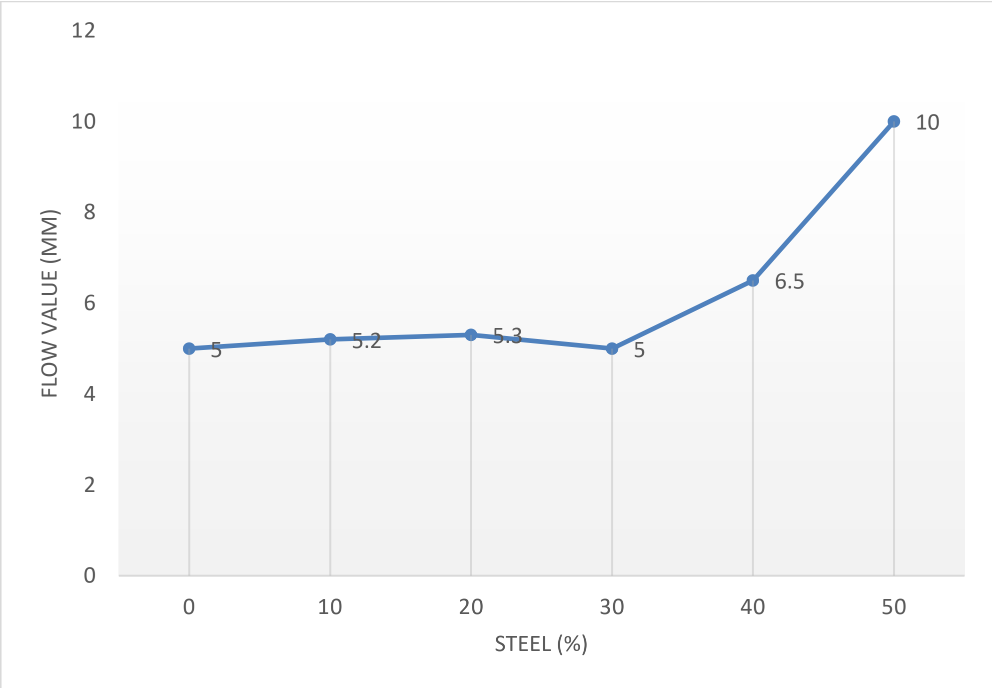

Figure 4.2 Marshall Flow Value (in mm) against varying Steel Shavings replacing fine aggregates.

Table 4.3 Marshall Stability Test Readings (Aluminum shavings replacing fine aggregates).

Sample	Marshall Stability (kg)	Marshall Flow (mm)
CBEM-N	455	5
CBEM-Al10	550	5.6
CBEM-Al20	683	6
CBEM-Al30	725	5.5
CBEM-Al40	800	6.2
CBEM-Al50	746	6.5

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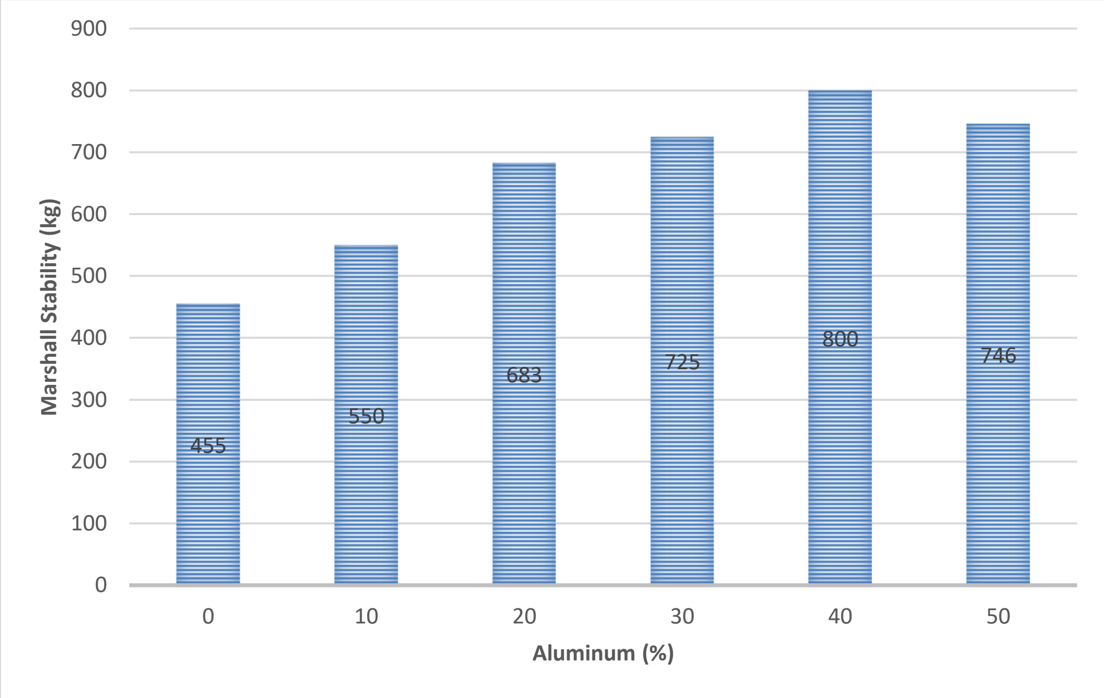

Figure 4.3 Marshall Stability (in kg) against varying Aluminum Shavings replacing fine aggregates

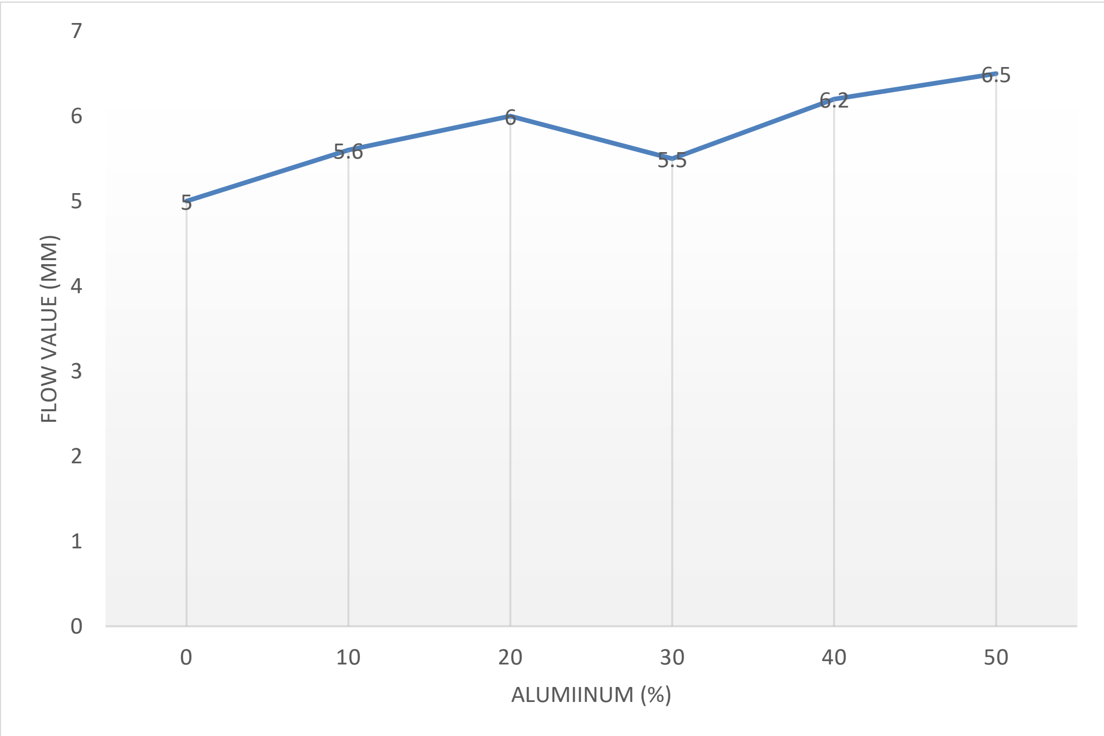

Figure 4.4 Marshall Flow Value (in mm) against varying Aluminum Shavings replacing fine aggregates.

Table 4.4 Indirect Tensile Strength for samples with Aluminum replacing fine aggregates.

Sample	ITS Value (kPa)
CBEM-N	200
CBEM-10Al	230
CBEM-20Al	245
CBEM-30Al	258
CBEM-40Al	282
CBEM-50Al	265

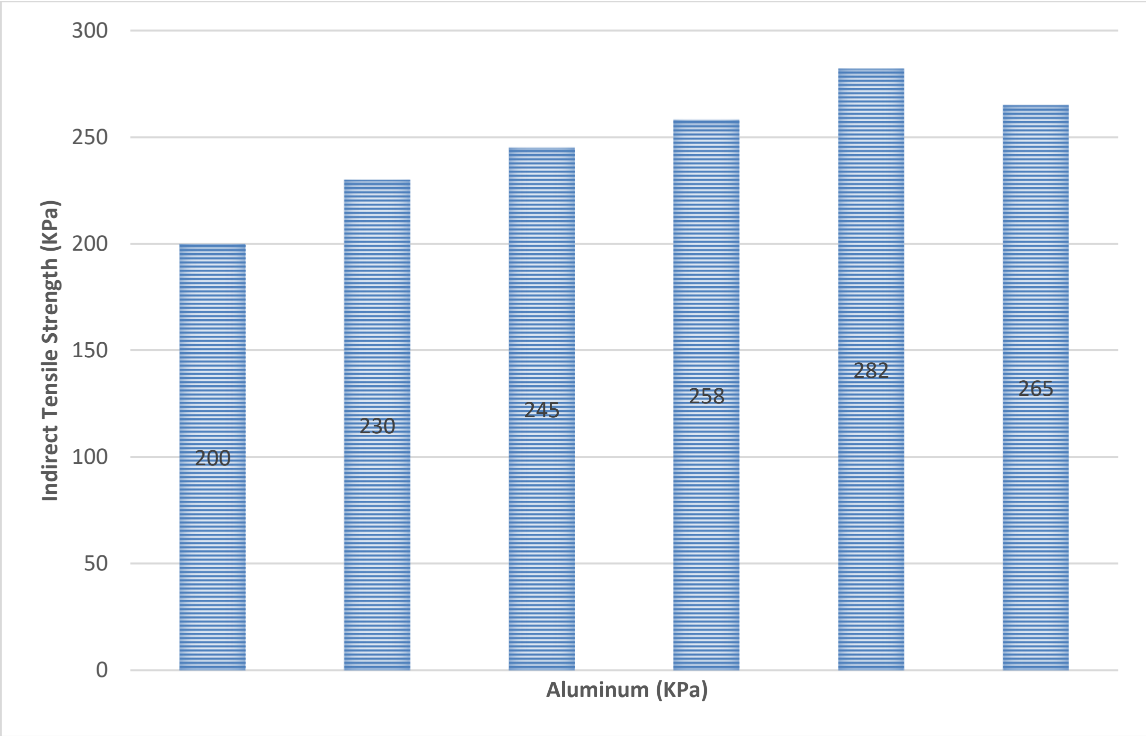

Figure 4.5 The comparison of Indirect Tensile Strength with varying Aluminum Shavings replacing fine aggregates.

Observations

- Results from Marshall Stability test suggest that Samples with 30 % of fine aggregates replaced with Steel shavings resulted in Highest Value of Marshall Stability 790 Kg and corresponding Flow Value of 5mm.
- Results from Marshall Stability test on samples in which fine aggregates were replaced with Aluminum shavings suggest that Marshall Stability was highest at 40% of fine aggregates replaced with Aluminum and the values of Marshall stability and Marshall Flow are 800 Kg and 6.2mm respectively.
- Results from Indirect tensile strength tests suggest samples with 30% of fine aggregates replaced by steel shavings had maximum value of ITS as 292 KPa.
- For samples reinforced with Aluminum shavings, sample with 40% of fine aggregates replaced by aluminum had ITS value of 282 KP

Observations from graphs:

- Steel being non-absorbent gets very less coating compared to sand, thus interlocking of aggregates is affected negatively. Thus beyond 30% of fine aggregates replacement with steel shavings Marshall Stability and Indirect tensile strength decreased whereas Marshall Flow increased.
- In case of samples in which 40% of fine aggregates was replaced by Aluminum shavings, a decrease in Marshall Stability and Indirect Tensile strength was observed due to negative impact of non-absorbent character of Aluminum on Interlocking of aggregates. However, Marshall Flow value increased.
- Also due to Compaction effort on samples (with steel shavings as reinforcement), there will be colder surfaces of aggregates coated with Emulsion and Steel shavings resulting in decrease in interlocking and Marshall Stability.

5. CONCLUSION

From the above studies based on the performance of cold mix following conclusions were drawn:

- In comparison to Normal samples (NCBEM), the Marshall stability of CMA samples reinforced with steel shavings resulted in enhanced strength up to 75% (at 30% of steel shavings replacing fine aggregates) whereas CMA samples reinforced with Aluminum resulted in enhanced strength up to 76% (at 40% of aluminum shavings replacing fine aggregates).
- Indirect tensile strength increased up to 46% on adding steel shavings up to 30% by weight of fine aggregates and as for Aluminum reinforced samples ITS increased only up to 40% (at 40% replacement of fine aggregates by Aluminum shavings).
- Beyond 30% of sand replacement with steel shavings and 40% of fine aggregates replaced with Aluminum shavings, there was a negative impact on Marshall Stability and Indirect tensile strength.

- In Cold mixes, due to colder surfaces of steel shavings and aggregates coated with emulsion, compaction effort has a negative impact on bonding and interlocking of aggregates which further leads to decreased in performance.
- The Non-Absorbent character of steel and aluminum impacts coating on aggregates and bonding/interlocking of aggregates thus resulting in decrease in performance of CMA samples.
- Samples reinforced with steel shavings showed better performance, thus got better results than samples reinforced with aluminum shavings.

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