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A Study on Utilization of Recycled Aggregate, Crusher Dust and Sand in Road Construction

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Abstract The construction of road networks requires substantial quantities of materials, and the availability of high-quality natural resources is becoming increasingly challenging. As road infrastructure expands through programs like Pradhan Mantri Rojgar Yojana (PMRY) and Jawaharlal Nehru National Urban Renewal Mission (JNNURM), the need for alternative materials is growing. This study explores the use of Recycled Aggregate, Sand, and Crusher Dust as replacements for conventional earth materials like crushed stone aggregates and natural sand in road construction. The aim is to evaluate the geotechnical properties of compacted Crusher Dust, Sand, and Recycled Aggregate mixtures and their suitability as road base and sub-base materials. Through a series of compaction and California Bearing Ratio (CBR) tests, the strength characteristics of these materials were assessed by varying the proportions of Sand (60% to 10%) and Crusher Dust (40% to 10%) in Recycled Aggregate mixtures. The experimental results indicate that a mix of 20-30% Sand and 20-30% Crusher Dust, combined with 60-70% Recycled Aggregate, yields satisfactory results for road base and sub-base layers, meeting the Ministry of Road Transport and Highways (MORTH) specifications. The maximum strength values were observed at 30-40% Crusher Dust with Recycled Aggregate, demonstrating the potential for these materials to serve as viable alternatives in road construction. Keywords: Recycled Aggregate, Crusher Dust, Sand, Road Base, Sub-base, CBR, Compaction, MORTH Specifications, Pavement Layers, Sustainable Construction

1.Introduction

India is a developing country and rapid economic growth of a country depends on its infrastructure development. Road networking is one such Infrastructure which transports mass, material from one place to the other. The performance of a pavement depends on the quality of the material used along with its component layers like SUB- GRADE, Sub-base & base courses. These component layers are generally made up of granular materials. These are compacted layers of morrum/gravel, aggregates, industrial wastes, mixtures etc. These have the capacity of spreading load to a wider area with causing minimum/no settlements and deformations such that reductions of excessive stresses on the subgrade.

The physical properties, chemical composition, and mineralogy of Crusher dust vary with aggregate type and producer source, but are relatively consistent at each Crusher location (Wood et al., 1993)". Crusher dust samples yielded high CBR values indicating its potential as a good material (Soosan et al. 2001). Engineering properties of soils are improved substantially by the addition of Crusher dust. Improvements are manifested in the form of reduction in liquid limit (LL), reduction in Plasticity, increase in Maximum Dry Density (MDD), decrease in Optimum Moisture Content (OMC) and increase in un-soaked (immediately after molding) and soaked (immersed in water for 96 h) CBR values. Soil and Crusher dust mixtures can be used advantageously as embankment material, backfill material and as a sub-base material (Soosan et al., 2000)20 In the analysis and design of geotechnical engineering structures made from or foundedon compacted soils are necessary to evaluate their stability and given the usage of waste materials as potential replacements for highway aggregates.

Recycling of concrete is a relatively simple process. It involves breaking, removing, and crushing existing concrete into a material with a specified size and quality. The quality of concrete with RCA is very dependent on the quality of the recycled material used. Recycled aggregate is produced by crushing concrete, and sometimes asphalt, to reclaim the aggregate. Recycled aggregate can be used for many purposes. The primary market is road base. Applications include partial replacement (up to 30% of coarse RCA) for virgin material in concrete production for non-structural works like general bulk fills, Bank protection, Base or fill for drainage structures, Road construction, Noise barriers and embankments etc.

The present work aims at evaluating the geo-technical properties of compacted Crusher dust along with the Recycled aggregate. The strength characteristics of compacted crusher dust are evaluated through a series of CBR tests and Compaction tests varying the crusher dust contents from 10% to 60%. The suitability of compacted crusher dust as a road base and sub-base material has been studied by conducting laboratory CBR tests.

This study explores the utilization of recycled aggregate, crusher dust, and sand in road construction, aiming to assess their performance and sustainability benefits. With increasing demand for construction materials and growing environmental concerns, incorporating recycled materials presents an effective solution for reducing waste and conserving natural resources The study involves a comprehensive analysis of the physical and mechanical properties of these materials, including gradation, compressive strength, and durability. Laboratory tests will be conducted to evaluate the performance of pavement mixtures containing recycled aggregates, crusher dust, and sand, focusing on their load-bearing capacity and resistance to environmental factors. Furthermore, the economic benefits of using these materials will be examined, highlighting potential cost savings in material procurement and disposal. Additionally, environmental impacts, such as reduced carbon footprint and landfill usage, will be assessed to support the adoption of these sustainable practices. Ultimately, the findings aim to provide guidelines for the effective use of these materials in road construction, promoting sustainable practices while meeting engineering standards and specification

2. Objectives

The main objective is utilization of Recycled aggregate, Crusher dust and Sand as sub-base, base Courses.

- Formation of gradation mixes of Recycled aggregate with Crusher dust and Recycled Aggregate with Sand.
- To know the Denseness of these mixes by performing compaction and gradation tests.
- To know the strength of these gradation mixes by performing CBR tests.
- Comparison of these gradation mixes with MORTH specifications and explanation for suitability of these mixes as sub-base, base and wet mix macadam layers.
- Fixing of optimal dosage of Crusher dust in place of Sand and Recycled aggregate in place of Crushed stone.

3.SCOPE OF THE PRESENT STUDY:

In this study, a comprehensive evaluation of natural and recycled materials used in pavement construction is undertaken, with the primary focus on understanding their performance characteristics, compaction properties, and overall suitability for flexible pavement layers. The materials selected for investigation include **sand from the** Nagavali river bed, recycled aggregate from demolished structural elements such as beams, columns, and slabs, and crusher dust sourced from local quarries. These materials were chosen based on their availability and potential as substitutes for conventional aggregates, given the increasing scarcity of natural resources.

Material Selection and Gradation

The materials used in this study were graded according to the standards outlined in **IS 2720-Part 4: 1985** and the **MORTH (Ministry of Road Transport & Highways) specifications**. A set of Indian Standard (IS) sieves were employed to achieve the required particle size distribution for various gradation mixes. The gradation process is crucial for determining the compaction characteristics and strength properties of these materials, as the distribution of particle sizes plays a significant role in their ability to form dense, well-compacted layers in pavement structures.

Gradation mixes were prepared using different combinations of sand, recycled aggregate, and crusher dust. These mixtures were subjected to **compaction tests** to determine their **Optimum Moisture Content (OMC)** and **Maximum Dry Density (MDD)**. The OMC refers to the amount of water required for achieving the highest possible dry density of the material under compaction, while the MDD represents the peak dry density that can be achieved for a particular mix. These parameters are essential for assessing the workability and compaction potential of the materials used in road construction.

Strength Evaluation Using CBR Tests

At the determined maximum dry densities, the strength characteristics of the various mixes were assessed through **California Bearing Ratio (CBR) tests**. The CBR test is a widely used method for evaluating the strength of sub-grade, sub-base, and base layers in flexible pavement design. It measures the resistance of a material to penetration under controlled conditions, simulating the pressure applied by traffic loads. The results of the CBR tests provide valuable insight into the load-bearing capacity of the materials, which is critical for ensuring the long-term performance and durability of the pavement structure.

The strength values obtained from the CBR tests were compared with the MORTH specifications to assess the suitability of the different mixes for use in various layers of flexible pavements. MORTH specifications set the minimum strength requirements for materials used in sub-base, base, and surface layers of roads, ensuring that the pavement can withstand traffic loads without excessive deformation or failure. By comparing the test results with these standards, the study provides a clear indication of whether the selected materials, in their respective gradations, meet the required performance criteria for road construction.

4.Materials and Methodology

4. 1 Types of Pavement Structures:

Based on the structural behavior, pavements are generally classified into three categories

- Flexible pavements.
- Rigid pavements.
- Semi Rigid pavements.

Flexible Pavements:

Flexible pavements are those, which on the whole have low or negligible flexural strength and are rather flexible in their structural action under the loads. The flexible pavement layers reflect the deformation of the lower layers on to the surface of the layer. Thus if the lower layer of the pavement or soil subgrade is undulated, the flexible pavement surface also gets undulated.

Flexible pavements are commonly designed using empirical design charts or equations taking into account some of the design factors. There are also semi empirical and theoretical design methods.

Rigid Pavements:

Rigid pavements are characterized by their significant flexural strength and rigidity, differentiating them from flexible pavements, which transfer stresses from grain to grain. Made from Portland cement concrete—whether plain, reinforced, or pre-stressed—rigid pavements can withstand flexural stresses of approximately 40 kg/cm². Their slab action allows them to distribute wheel load stresses over a broader area beneath the surface.

The structural behavior of rigid pavements differs fundamentally from that of flexible pavements. In rigid pavements, the critical stress condition arises from maximum flexural stress, which occurs in the slab due to wheel loads and temperature fluctuations. In contrast, flexible pavements primarily deal with the distribution of compressive stresses. As rigid pavement slabs possess tensile strength, bending under wheel loads and temperature changes induces tensile stresses. This results in distinct types of stresses and their distribution within the cement concrete slab compared to flexible systems.

Additionally, rigid pavements maintain their shape and do not conform to the lower layers, allowing them to bridge minor variations in the subgrade. This quality contributes to their durability and longevity.

In our experimental work, we investigate the mechanical properties of pervious concrete, incorporating Ground Granulated Blast-Furnace Slag (GGBS) as a mineral admixture and cellulose fiber as reinforcement. This approach aims to enhance the performance characteristics of pervious concrete, providing insights into its potential applications in sustainable pavement solutions.

Semi Rigid Pavements:
When bonded materials like the pozzolanic Concrete (lime-fly ash aggregate mix), lean cement concrete or soil-cement are used in the base course or sub-base course layer, pavement layer has considerably higher flexural strength than the common flexible pavement layers. However, these bonded materials do not possess as much flexural strength as the cement Concrete pavements. Therefore, when this intermediate class of materials is used in the base or sub-base course layer of the pavements, they are called semi rigid pavements. This third category of semi-rigid pavements are either designed as flexible pavements with some correction factors to find the thickness requirements based on experience, or by using a new design approach. These semi-rigid pavement materials have low resistance to impact and abrasion and therefore are usually provided with flexible pavement surface course.

4.2 Components of Flexible and Rigid Pavements:
A typical Flexible Pavement consists of four components

- Soil sub-grade.
- Sub-base course.
- Base course.
- Surface course.

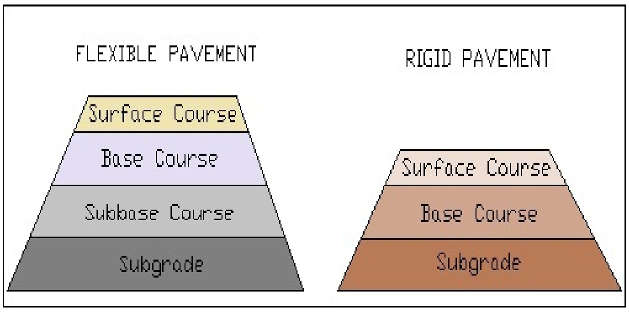


Fig1: Components of Pavements

Flexible pavements transmit vertical or compressive stresses to the underlying layers through grain-to-grain transfer at the points of contact within the granular structure. A well-compacted granular assembly, composed of well-graded aggregates (with or without binder materials), effectively transfers compressive stresses over a wider area, making it an essential component of a robust flexible pavement layer. The load distribution capability of this layer is influenced by both the material types and the mix design parameters.

Bituminous concrete is recognized as one of the premier materials for flexible pavement layers. Other materials in this category include various granular substances, with or without bituminous binders, such as Water Bound Macadam, crushed stone aggregates, gravel, and soil-aggregate mixtures. The vertical compressive stress is highest at the pavement surface directly beneath the wheel load and corresponds to the contact pressure exerted by the wheel.

Thanks to the ability to distribute stresses over a larger area in the form of a truncated cone, the intensity of stresses decreases in the lower layers. This characteristic of flexible pavements led to the development of the layer system concept. According to this approach, flexible pavements can be constructed in multiple layers, with the top layer designed to be the strongest. This layer bears the highest compressive stresses, in addition to enduring wear and tear from traffic.

In contrast, the lower layers experience lesser stress magnitudes and do not face direct wear from traffic loads. Thus, these layers can incorporate inferior materials at a lower cost. The foundational layer is the prepared surface, consisting of local soil, known as the sub-grade, which has the least stability among the four primary components of flexible pavements.

A typical cross-section of a flexible pavement structure includes several layers. The top layer is the wearing surface, followed by the base course, and then the sub-base course. The lowest layer comprises the soil sub-grade. Each layer above the sub-grade—namely the sub-base, base course, and surface course—can consist of one or more layers of similar or slightly different materials and specifications. This multi-layered structure allows for effective stress distribution, enhancing the overall performance and longevity of flexible pavements while optimizing construction costs.

4.3 Functions of Pavement Components:
Pavement is a vital part of transportation infrastructure, providing a durable surface for both vehicular and pedestrian traffic. The effectiveness and longevity of a pavement system hinge on the appropriate design and function of its various components. Each layer in a pavement structure fulfills a specific role, making it essential to understand these functions for efficient design, construction, and maintenance.

Pavement components typically consist of the surface layer, base course, sub-base, and subgrade. The surface layer offers a smooth and durable riding surface, enhancing safety and comfort for users. Beneath this, the base and sub-base layers work together to distribute loads and provide structural support, preventing deformation and failure. The subgrade, which is the natural soil lying beneath the pavement, must be adequately prepared to handle the stresses transmitted from the upper layers.

Together, these components ensure effective load distribution, durability, proper water drainage, and resistance to environmental impacts. This collective function is crucial for maintaining the integrity and performance of the pavement over time. Understanding the individual roles of each pavement component sets the stage for a detailed discussion on their contributions to the overall pavement system, highlighting their importance in achieving a long-lasting and efficient infrastructure.

4.4 Soil Sub-grade and its Evaluation

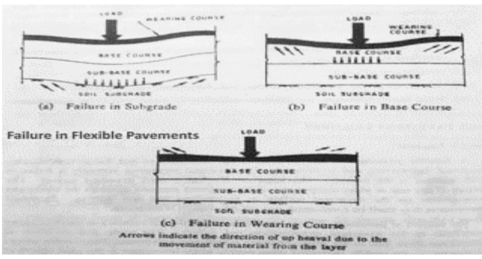
The soil sub-grade serves as a crucial layer of natural soil, prepared to support the pavement materials placed above it. It is essential for this layer to adequately receive and disperse the loads from the pavement without becoming overstressed. This means that the pressure exerted on the top of the sub-grade must remain within allowable limits to avoid excessive stress or deformation beyond the elastic limit. Therefore, it is recommended that the top 50 cm of the sub-grade soil be well compacted under controlled conditions, considering optimum moisture content and maximum dry density.

Evaluating the strength properties of the soil sub-grade is necessary for effective pavement design. This assessment allows designers to adopt suitable strength parameters, and if the soil does not meet expectations, it can be treated or stabilized as needed. Several tests are available to measure the strength properties of sub-grades, most of which are empirical and useful for correlation in design.

Common strength tests for evaluating soil sub-grade include the California Bearing Ratio (CBR) test, California Resistance Value test, Triaxial Compression test, and Plate Bearing test. The CBR test, a penetration test, is widely used in flexible pavement design, conducted either in the laboratory or in situ. The California Resistance Value test is determined using a Hveem stabilometer, while the Triaxial Compression test, although significant, is less commonly used in pavement design. The Plate Bearing test assesses the load-bearing capacity and elastic modulus of the sub-grade and other pavement layers, providing valuable data for various flexible and rigid pavement design methods.

4.5 Failures in Flexible Pavements

Failures in flexible pavements occur due to various factors like traffic loads, environmental conditions, and poor design or construction. Common types include rutting (permanent deformation), fatigue cracking (due to repeated loads), and potholes (surface disintegration). These failures reduce pavement performance, requiring timely maintenance to prevent further deterioration.As stated above, the localized settlement of any one component layer of the flexible pavement structure could be enough to cause pavement failure. This demands that each one of the layers should be carefully designed and laid. Thus to maintain the stability of the pavement structure as a whole, each layer should be stable within itself and thereby make the total pavement maintain its stability, Figure 3.2 illustrates the above concept. Figure 3.2-a, b and e illustrates the failures in the soil sub-grade, base Course and the surface or wearing course. It may be seen that.



4.6 Failures in Flexible Pavements

Failures in Sub-grade:

One of the prime causes of flexible pavement failure is excessive deformation in sub-grade soil. This can be noticed in the form of excessive undulations or waves and corrugations in the pavement surface and also depressions followed by heaving of pavement surface. The lateral shoving of pavement near the edge along the wheel path of vehicles is due to insufficient bearing capacity or a shear failure in sub-grade soil. Excessive unevenness of pavement surface is considered as pavement failure.

4.7 The failure of sub-grade may be attributed due to two basic reasons:

- Inadequate stability.
- Excessive stress application.

If the applied stress on the sub-grade or pavement is very low when compared to its bearing capacity, the deformation due to the load would be elastic or fully recovered when the load is released. If the compaction of the layers is not adequate with reference to subsequent loading, part of the deformation may be permanent due to compaction of soil, this may be called as consolidation deformation. But if the applied stress is excessive with respect to the stability and if plastic flow takes place as in the case of wet clayey soil, this deformation is called plastic deformation and is not even partly recoverable. These have been illustrated in Fig 3.2.

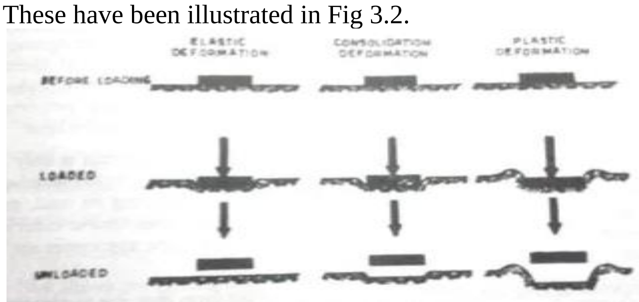


Fig 3. Soil Deformation under Loads

The type of damage in flexible pavement that can be caused by traffic due to sub- grade failure or due to inadequate and improper compaction of sub-grade and other pavement layers has been illustrated in Fig 3.3

5. Results and Discussions

The performance of a pavement is indicative of the proper functioning of its component layers. Key factors influencing the design period, life expectancy, durability, and maintenance costs of the pavement are the selection and characterization of materials used. The primary component layers include the sub-base and base courses, which have a direct impact on the functionality of the sub-grade. Historically, materials such as gravel and morrum were commonly utilized as sub-base materials. However, the presence of plastic fines and their sticky properties have hindered pavement performance due to moisture absorption and the resulting continuous plastic deformation.To mitigate these issues, it is essential to select materials that reduce the stress on the sub-grade, enhance the drainage capabilities of the sub-base course, and ultimately improve the overall durability of the pavement. Both the sub-base and base courses should be devoid of plastic particles that deform when in contact with water, as this can lead to various failures and incompatibilities between the component layers.Potential materials for the sub-base and base courses include natural soils (such as gravels and morrum), natural stone particles (coarse aggregates), sand, and industrial by-products. Notable industrial wastes suitable for use in these layers include steel slag, copper slag, zinc slag, pond ash, fly ash, Rice Husk Ash (RHA), Ground Granulated Blast Furnace Slag (GGBS), and crusher dust.

This study aims to explore the utilization of mechanically stabilized recycled aggregates and crusher dust mixes as effective materials for sub-base and base courses. By integrating these materials, the research seeks to enhance pavement performance while promoting sustainable practices in construction.

Table 1: Gradation of sand

Sieve Sizes (mm)	% Finer
4.75	**100**
2.36	**97**
1.18	**92**
0.6	**77**
0.3	**15**
0.15	**2.0**
0.425	**3.84**
C_u	**2.07**
Cc	**1.41**
ZONE-III	

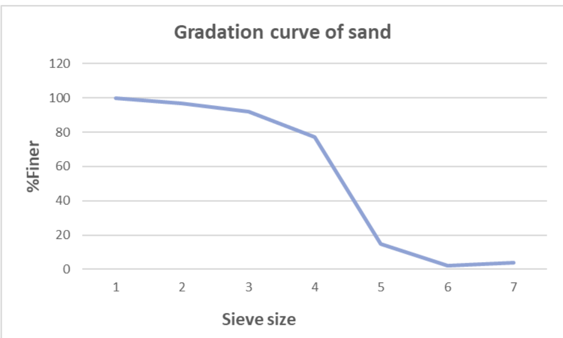
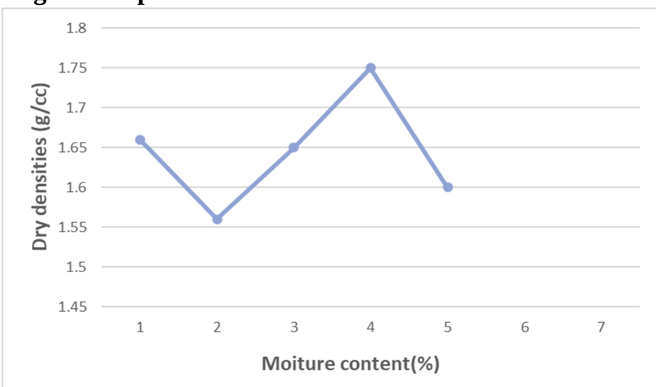


Fig 4: Particle size distribution curve of Sand

Table 2. Compaction values of Sand

Water content (%)	Dry density (g/cc)
2	1.66
3.5	1.56
5	1.65
6	1.75
8	1.6

Fig 5: Compaction curve for Sand



From the test results of Sand, the following identifications are made. Majority of sand particles are under medium to fine sand range. The gradation also shows it comes under zone III. Based on BIS it is classified as poorly graded sand with non-plastic in nature. SP with C-2.07 and C-1.44

The compaction curve for sand illustrates the relationship between the moisture content and the dry density of the sand when subjected to compaction. Typically represented as a graph, it shows an optimum moisture content at which maximum dry density is achieved.

Recycled aggregate + Sand (% Finer)						
Sieve Sizes (mm)	**G1 (RCA 40-S60%)**	**G2 (RCA 50-$50%)**	**G3 (RCA 60-S40%)**	**G4 (RCA 70-$30%)**	**G5 (RCA 80-S20%)**	**G6 (RCA 90-S10%)**
53	**100**	**100**	**100**	**100**	**100**	**100**
26.5	**90**	**90**	**80**	**80**	**80**	**70**
9.5	**80**	**70**	**60**	**60**	**50**	**40**
4.75	**60**	**50**	**40**	**30**	**20**	**10**
2.36	**58**	**49**	**39**	**29**	**20**	**10**
0.425	**14**	**12**	**9**	**7**	**5**	**2**

0.075	**1**	**1**	**1**	**1**	**1**	**1**

Table 2; Recycled Aggregate with Sand Mixes

Recycled aggregate +sand (% finer)						
Sieve Sizes	**GI**	**G2**	**G3**	**G4**	**G5**	**G6**
	(RCA 40-S60%)	**(RCA 50-S50%)**	**(RCA60-$40%)**	**(RCA 70-$30%)**	**(RCA80-S20%)**	**(RCA90-$10%)**
53	**100**	**100**	**100**	**100**	**100**	**100**
26.5	**90**	**90**	**80**	**80**	**80**	**70**
9.5	**80**	**70**	**60**	**60**	**50**	**40**
4.75	**60**	**50**	**40**	**30**	**20**	**10**
Compaction characteristics						
OMC	**4.8**	**4.6**	**4.3**	**4.1**	**3.8**	**3.6**
MDD	**2.14**	**2.16**	**2.19**	**2.22**	**2.2**	**2.16**

Table;3 OMC and MDD values for Recycled Aggregate and Sand Mixes

Recycled aggregate with Sand (% Finer)						
Sieve Sizes (mm)	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
	(RCA40-S60%)	**(RCA 50-S50%)**	**(RCA 60-$40%)**	**(RCA70-$30%)**	**(RCA 80-S20%)**	**(RCA90-$10%)**
53	**100**	**100**	**100**	**100**	**100**	**100**
26.5	**90**	**90**	**80**	**80**	**80**	**70**
9.5	**80**	**70**	**60**	**60**	**50**	**40**
4.75	**60**	**50**	**40**	**30**	**20**	**10**
Strength characteristics						
Soaked CBR (%)	**18**	**28**	**42**	**56**	**54**	**40**
Void ratio (%)	**0.27**	**0.26**	**0.25**	**0.22**	**0.27**	**0.3**
Specific Gravity (G)	**2.71**	**2.73**	**2.75**	**2.77**	**2.8**	**2.82**

Table.4 Strength Characteristics of Recycled Aggregate with Sand

Recycled Concrete Aggregate (RCA): Comprising crushed concrete from demolished structures, RCA varies in particle size, texture, and shape, influencing the overall density of the mix. Its angular particles can improve interlocking, potentially enhancing compaction.

Crusher Dust (CD): This fine material, produced during the crushing of stones, can fill voids in the RCA, contributing to a denser mix. By replacing 50% of sand with CD, the overall particle size distribution is altered, affecting the packing and density.

Sand: Traditionally used as a fine aggregate, sand has a lower specific gravity than RCA and CD. Its replacement with CD can lead to variations in MDD due to the different characteristics of the materials.

The use of RCA with 50% CD replacement in place of sand can produce an economical and sustainable material for various construction applications, including road bases, sub-bases, and fill materials. The resulting mix may offer improved mechanical properties, such as increased strength and durability, making it suitable for supporting traffic loads.

The MDD of a mix containing RCA and 50% CD as a partial replacement for sand is an essential consideration in material design for construction projects. Understanding the density characteristics of this blend can inform engineers and construction professionals about its suitability for specific applications, ultimately contributing to more sustainable practices in the construction industry. Further research and experimentation may provide deeper insights into optimizing this mix for various engineering applications.

Utilizing RCA with 50% CD as a replacement for sand can create a cost-effective and eco-friendly material suitable for a range of construction applications, such as road bases, sub-bases, and fill materials. This innovative blend can enhance mechanical properties, resulting in greater strength and durability, making it well-suited for withstanding traffic loads. Moreover, this combination minimizes the environmental impact by reducing waste and conserving natural resources. The use of recycled materials aligns with sustainable construction practices, promoting a circular economy in the building industry. By adopting these materials, construction projects can achieve both performance efficiency and environmental responsibility, contributing to a greener future.

6.Conclusions

1. Recycled Aggregate and Crusher Dust mixes attained higher CBR values of 75% at a dosage of 20-30% of Sand.
2. Dense packing attained at a dosage of 20-30% of Sand with respect to Maximum Dry Density is 2.22(g/cc).
3. Mixes attained CBR values greater than 30% can be used as sub-base Course and > 50 can be used as a base course material.
4. In partial replacement of Sand by Crusher dust at 15-20% dosage yielded good results.

5. At 15-20% of dosage of Crusher dust CBR values > 50 can be used as sub-base and Base courses.
6. 20-30% of Sand as a whole or 15-20% of Crusher Dust with Sand of Maximum Fine Aggregate not exceeding 30% with respect to Recycled Aggregate can be used as Sub-base and Base courses.
7. It is identified that 15-20% of Crusher Dust in place of Sand with respect to 70% of recycled Aggregate in place of Crushed stone aggregate attained best Geotechnical Characteristics such as Compaction, Strength etc

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