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Improvement of Strength Characteristics of Sub-Base/Base Course using Cement, Pond Ash and Recycled Aggregate

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***Abstract:* Highways are the most common public work facilities for transportation. Early provision of a large network of cheap yet efficient roads is of vital importance to the rapid development of the country. Further, the demand for a greater mileage of roads with fast developing economy of India and with restricted amount of finances makes it obligatory utilizing the local materials for Highway construction. The conventional methods and materials of road construction, maintenance and operation consume enormous resources. There are many number of routes on which less traffic justifies only low-cost type pavements. For important routes where there is enormous increase of traffic, the importance of adequate base course and sub base has substantially increased and they should possess more strength than previously required. Soil stabilization provides an answer to the problem as various waste materials can be successfully used for stabilization.**

This study has been conducted to investigate the effects of replacement of Natural Coarse aggregate (NCA) by Recycled concrete aggregate (RCA) and use of pond ash (PA) and cement as stabilizing agents on the strength characteristics of sub-base/base course. For pond ash, the disposal is quite a costly affair for the coal burning utility plants, can be very conveniently used for the economical construction of low cost roads having treated surfaces and for the stabilization of base/sub-base underneath the high type flexible or rigid pavements

Keywords: Concrete, Highway, Pond ash, Pavements

I. INTRODUCTION

A. General

The emphasis was given to increase the sustainability of environment and better ways have been explored to manage wastes materials such as coal ash, plastic, rubber, construction and demolition waste, broken glass, scrap tyres, steel furnace slag etc. which are creating a number of problems in handling and disposing. These waste materials are disposed off either in low lying areas or in land fill sites which result in filling of land fill site at a very fast rate. So, reducing, reusing and recycling are the need of hour to save the natural resources as well as to save the land fill site which are otherwise going to create space problems for disposal of waste material. It is estimated that 10-12 million tons of construction and demolition waste (CDW) is generated in India every year which needs a huge space for disposal. It is also surveyed that there is a huge deficit of about 750 million cubic meter aggregates to achieve the targets of road sector in India (www.urbanindia.nic.in). So, CDW can prove to be very useful to meet the demand and supply gap of road sector. The bricks, metal and wood items are reused in new construction but the concrete and masonry waste which forms more than 50% of CDW are still not recycled in India. Therefore, there is need to recycle these concrete waste which are creating disposal problem in construction industry. These recycled concrete aggregates (RCA) which are cheaply available from construction and demolition sites can be used in highways construction *i.e.* in base or sub-base layers of pavement. As the finance and funds are major problem in construction of rural roads, RCA can prove to be best alternative for rural roads which is cheap and sustainable option.

There are many advantages that lead to the use of RCA materials as pavement material in bases/sub-bases of roads. The main advantages of using RCA in the construction industry are of sustainable values and environmental issues. The wastes from construction and demolition works are of large volume and increasing over time. To overcome this issue, sustainable construction is one of the strategies to be considered by the construction industry. One way of achieving this is to introduce recycled aggregates from these wastes of construction and demolition works in to pavements.

B. Objectives

A lot of old buildings in India are collapsed or replaced every year. As a result, the demolished debris from the structures is to be disposed either in low lying areas or to landfills or it may be gainfully utilized in the construction of highways as sub-base or base layer after grading it. After crushing the RCA to proper gradation, these can be used in pavement base/sub-base course. The mechanical and durability properties of recycled aggregate can be improved using admixing agents like cement, coal ash, lime etc. and treated material can be used in pavement layers.

In the present work, the effects of addition of admixtures as binary blend on strength characteristics of concrete are investigated. The precise objectives of the study are as follows:-

1) The main objective of this research is to understand better the mechanical behavior of recycled mixtures in order to evaluate whether they are gainfully useful as granular material in the base or sub-base layer of road pavement. Moreover, RCA mixtures treated with admixtures are investigated to evaluate the improving range in mechanical performance.
2) To analyze the cost of construction of flexible pavement with RCA mixture sub-base and compare the cost with pavement comprises of moorum sub-base course on a rural road where finance and funds are major problems for their development. Moreover, stage construction is done for the design and development of rural roads where these cheap recycled materials can be gainfully used.

II. LITERATURE REVIEW

A. General

Nowadays concrete is the most widely used construction material. Durability is one of the most important considerations in the design of new structures and assessing the condition of existing structures. The last 20 to 30 years have seen a growing awareness amongst engineers of the need to ensure that provisions are made for durability in component of pavement structures. More recently, there has also been a growing awareness of the importance of sustainability in pavement construction and in particular the more effective and efficient use of materials.

This chapter deals with the review of the existing literature on the use of RCA in base and sub-base layer of pavement. The most important investigations, related to the current investigation, are summarized and salient facts which seem to emerge from the research discussed. The discussion is generally confined to the strength and durability characteristics of pavement layer with RCA and mineral admixtures such as pond ash (PA).

B. Review of past works

Scientific knowledge on the potential for the use of recycled concrete aggregates in unbound road applications has advanced considerably. In India and many countries and regions, however, the production of recycled concrete aggregate is much lower than the generation of mixed recycled aggregate obtained from the treatment of mixed rubble. This is made up of materials of various types, such as concrete, ceramics, asphalt, natural stone, as well as organic impurities (such as wood, plastic, and paper-cardboard), and inorganic impurities (metal and gypsum).

Vegas et al. (2011) constituted a scientific working document for regulating the use of recycled aggregates obtained from the treatment of mixed rubble in unbound structural road applications. In the short term, the intention was to continue this work by investigating the conditions of use of recycled aggregates of this type in bound applications with cement and lime, applying stricter criteria with regard to mechanical performance and durability.

Arulrajah et al. (2012) considered a comprehensive laboratory evaluation of the geotechnical properties of five predominant types of construction and demolitions (C&D) waste materials. The C&D materials tested were recycled concrete aggregate (RCA), crushed brick (CB), Waste Rock (WR), Reclaimed asphalt pavement (RAP), and Fine Recycled Glass (FRG). The geotechnical assessment included particle size distribution, particle density, water absorption, compaction, Los Angeles abrasion, post-compaction sieve analysis, flakiness index, hydraulic conductivity, and California bearing ratio (CBR) tests. Shear strength properties of the materials were studied through a series of tri-axial tests. In terms of usage in pavement sub-bases, RCA and WR were found to have geotechnical engineering properties equivalent or superior to that of typical natural granular sub-base materials. CB at the lower target moisture contents of 70% of the OMC was also found to meet the requirements of typical quarry granular sub-base materials. The properties of CB, RAP, and FRG, however, may be further enhanced with additives or mixed in blends with high quality aggregates to enable their usage in pavement sub-bases

Cerni et al. (2012)provided a practical and innovative method for ranking granular material for pavement design on the basis of a performance-related approach such as permanent deformation analysis; on the other, they supported the use of construction and demolition materials as a sustainable and cost effective alternative to traditional aggregates.

Arulrajah et al. (2012) investigated the recycled crushed brick when blended with recycled concrete aggregate and crushed rock for pavement sub-base applications. The research indicates that up to 25%, crushed brick could be safely added to recycled concrete aggregate and crushed rock blends in pavement sub-base applications. The repeated load tri-axial test results on the blends indicate that the effects of crushed brick content on the mechanical properties in terms of permanent deformation and resilient modulus of both the recycled concrete aggregate and the crushed rock blends were marginal compared to the effects on dry density and moisture content.

Park (2003)tested the physical and compaction properties of two different recycled aggregates obtained from a housing redevelopment site (RCA1) and a concrete pavement rehabilitation project (RCA2). The bulk specific gravity and water absorption values were 2.53% and 2.54% and 1.43% and 1.77% for RCA1 and RCA2, respectively. The optimum moisture contents were found to be 9% and 12.8%, and the corresponding dry densities were 2.21 and 1.81 mg/m^3 for RCA1 and RCA2, respectively. It was apparent that the optimum moisture content increased with an increase in water absorption of the aggregates

Arulrajah et al. (2012) indicated that, at a density ratio of 98% compared to maximum dry density obtained in the modified proctor test and with moisture contents in the range of 65–90% of the optimum moisture content, most of the recycled C&D materials produce comparatively smaller permanent strain and greater resilient modulus than natural commonly used granular sub-base materials in pavement sub-base applications.

III. EXPERIMENTAL PROGRAMME

A. General

The main objective of test programme is to study strength characteristics of recycled concrete aggregate with pond ash and cement as admixture. The main parameters that are studied include U.C.S and C.B.R. To carry out this the equipment used, aggregates tested, experimental procedure adopted and the parameter studied have been elaborated in this chapter. Samples having various proportions of pond ash, recycled concrete aggregates, and cement contents are prepared for the present series of tests. RCA stands for recycled concrete aggregates. Sample prepared by mixing 10% pond ash by weight is designated as PA_{10}. In a similar lines sample PA_{20} had 20% pond ash of the total weight of the mix.

B. Recycled Concrete Aggregates (RCA)

Sufficient quantity of concrete aggregates is collected from demolition site in Village Nidani near Distt. Jind - Haryana. The main source of recycled concrete aggregate was beams and slabs which was free from any other contaminants. The aggregates are crushed manually with hammer and sieved through 25 mm, 19 mm, 10 mm, 4.75 mm, 2.36 mm, 425 micron, and 75 micron IS sieves for proper gradation of recycled aggregates. The coarser and finer fractions of RCA are designated by RCA-I and RCA-II respectively as stated earlier.

C. Pond ash

Pond ash is a byproduct of many thermal power stations. Pond ash resembles pozzolana i.e. various substance which although not cementitious itself contains constituents which combine with lime to form a material having cementitious properties. It is acidic in nature and its main constituents are silica, aluminum oxide and ferrous oxide. The pond ash is used in the present study is taken from Rajiv Gandhi Thermal Power Plant, Kedar and stored in dry containers. The Pond ash is added with recycled concrete aggregates in 10% and 20%.

D. Cement

Portland Pozzolana Cement (PPC) from a single lot was used throughout the investigation.

E. Water

Ordinary potable water from tap is used throughout the study. The water is neat, clean, and without any suspended material.

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F. Prepation of Soil Sample

The aggregates are crushed manually and sieved through 25mm, 19mm, 10mm and 4.75 mm IS sieves for proper gradation of recycled aggregates. The sieved material is then stored in bags. For each test required quantity of aggregates is taken from bags and dried in an oven at 100 Celsius at 24 hours. The aggregates are allowed to cool for 1-2 hours at room temperature. Pond ash is collected from Rajiv Gandhi Thermal Power Plant at Kedar (Haryana). The cement used for testing is Jaypee Cement (PPC) purchased from the local cement market. The materials (RCA, pond ash, cement and water) are mixed with the help of trowel for five to ten minutes and specimen is prepared with the mixture.

G. Moisture Density Relationship

It is necessary to make use of compacted soils or fills in the construction of roads and air- field runways. The soil is placed in compacted state because compaction of soil increases its strength, decrease further settlements and decreases permeability. The important factors in determining the maximum density attainable for a particular soil are the type of compaction, the compacting energy and water content. Since the compacting energy is fixed according to the compaction process used in the field, the purpose of a laboratory compaction test is to determine the optimum moisture content for the soil being tested. This gives us an indication of the amount of water to be used in the field while compacting the soil and the degree of denseness to expect as a result of compaction. It is, thus, necessary to have a laboratory test which will give a degree of compaction comparable to that by the field methods. Knowledge of moisture density relationship, as determine by a laboratory test, therefore make possible a better field control of the compacted fill.

Laboratory compaction tests are either dynamic or static, the former are used much more than the later because they lead to a more uniform density throughout the mass. Hence the modified proctor compaction test is run for determining the optimum moisture content and maximum dry densities. The test is proceeding according to the tentative method I.S. 2720 (8) using a 150mm (internal diameter), 127.3 mm high mould having 2250 cm^3 as the volume and standard hammer of 2.6 kg. Weight with a fall of 310 mm. 55 blows on each 3 layers of soil for light compaction of soil cement mix. The moisture density relationship is determined for the RCA-pond ash-cement mix. Soil, cement and pond ash are first dry mixed thoroughly by kneading manually till a uniform colour is obtained. Water is then added and the mixture again kneaded manually to obtain thorough mixing. The test is then carried according to I.S. 2720 (8).

H. Unconfined compression test

For cement treated mixtures, compressive strength tests are conducted where the preliminary cement content by weight was selected. The unconfined compressive strength (UCS) values for aggregate mixtures are obtained by testing cylindrical specimens of dimensions 150 mm diameters with 300 mm height (length/diameter ratios of about 2.00) using steel molds. The cast specimens are kept in ambient temperature for 24 hours, after de-moulding, the specimen are kept in curing tank for a total period of 7 days at a temperature of 27 ± 2 ºC. After curing for 7 days, the specimens are tested in compression testing machine at a rate of 1.25 mm/ minute and the maximum load is recorded. It is desirable to prepare and test three specimens each in order to find the average value of the compressive strength at different cement content.

A graph was plotted with cement content versus average compressive strength. The cement content of the mix corresponding to desired average compressive strength is obtained from the graph. Strength criteria have not been specified for soil cement mix design for use in India. As per the British Standards a minimum compressive strength of 17.5 Kg/cm^2 is considered desirable (Figure 1)

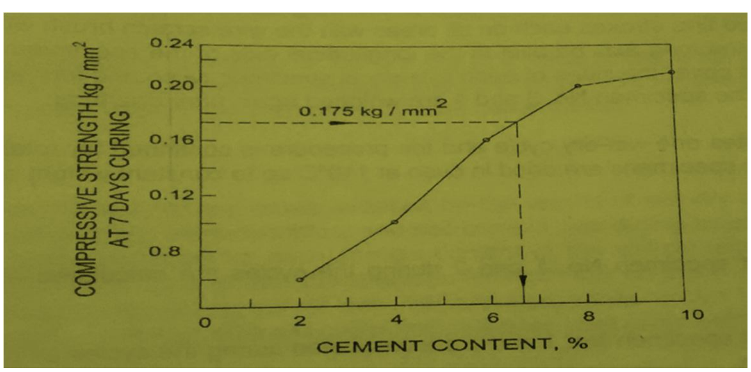

Fig 1: Soil- cement mix design (based on compressive strength)(Khanna & Justo, 2012)

I. California Bearing Ratio Test

The California bearing ratio test usually abbreviated to C.B.R. test is an adhoc penetration test for the evaluation of pavement layer strength and is used extensively in semi empirical methods of designing the thickness of pavements of roads and airports pavements. These tests determine the penetration resistance of a compacted specimen of soil by measuring the load required to cause a plunger of standard size to penetrate the soil at a standard rate. Before carrying out the test, soil specimen is usually soaked in water for 4 days to compare with worst field conditions. The determined resistance divided by the standard resistance (obtained from tests on crushed stone which was defined as having C.B.R. value of 100%) multiplied by 100 is calculated and that is the C.B.R. value.

IV. EXPERIMENTAL RESULTS

A. General

The experiments are conducted on recycled concrete aggregates (RCA) mixed with different percentages of cement and pond ash. The main parameters that are studied include compressive strength and C.B.R. Effect of addition of pond ash and cement in mix on the U.C.S and C.B.R values is studied in this investigation. The experimental results are carried out in the following laboratory works.

B. Grain size distribution

A suitable grading for testing is taken from Ministry of Road Transport and Highways which can be used for base/sub-base course in pavements. The recycled concrete aggregates are designated as RCA-I and RCA-II where RCA-I is the courser fraction *i.e.* plus 4.75 mm sieve size and RCA-II isthe finer fraction *i.e.* minus 4.75 mm sieve size. The grading requirements Base and Sub-base courses as per Ministry of Road Transport and Highways (specifications for road and bridge works) are given in Table 4.1. A suitable grading is taken for the samples which lie within the range of grading suggested by Ministry of Road Transport and Highways (MoRTH). The percent passing taken for preparing the sample is shown in last column of Table 2.

Table 2 - Grading for base and sub-base course of pavement

Type	Sieve (mm)	% passing for Sub-base Layer	% passing for Base Layer	% passing taken for preparing samples
RAC-I	75	100	100	100
	53	100	100	100
	26.5	95-100	95-100	100
	19	-	45-100	90
	9.5	50-80	35-100	65
	4.75	40-65	25-100	50
RCA-II	2.36	30-50	-	35
	.600	-	8-65	25
	.425	15-25	5-40	20
	0.075	3-10	0-10	10

C. Compaction of soil is a process by which the soil particles are constrained to be packed more closely together by reducing the air voids. It causes decrease in air voids and consequently increases in dry density. This may result in increase in shearing strength. Degree of compaction is usually measured quantitatively by dry density. Compaction refers to a more or less rapid reduction mainly in the air voids under a loading of short duration. Increase in dry density of soil due to compaction mainly depends on two factors.

1) Compacting moisture content
2) The amount of compaction.

Calculation

Wet density (gm/cc) = $\text{weight of compacted soil} / \text{capacity of mould.}$

Dry density $= \frac{\text{wet density}}{1+w}$

Where w is the moisture content of the soil.

D. Compaction Test Of Recycled Aggregates With Different Percent Of Pond Ash And Cement

Table 3

S.NO.	Soil Mix- RCA-I : RCA-II : Pond Ash	Cement content	MDD (gm/cc)	OMC (%)
1	50:40:10	2 %	1.894	7.1
2	50:40:10	4 %	1.895	7.4
3	50:40:10	6 %	1.897	7.9
4	50:40:10	8 %	1.903	8.6
5	50:30:20	2 %	1.753	9.1
6	50:30:20	4 %	1.767	9.6
7	50:30:20	6 %	1.781	10.1
8	50:30:20	8 %	1.790	10.5

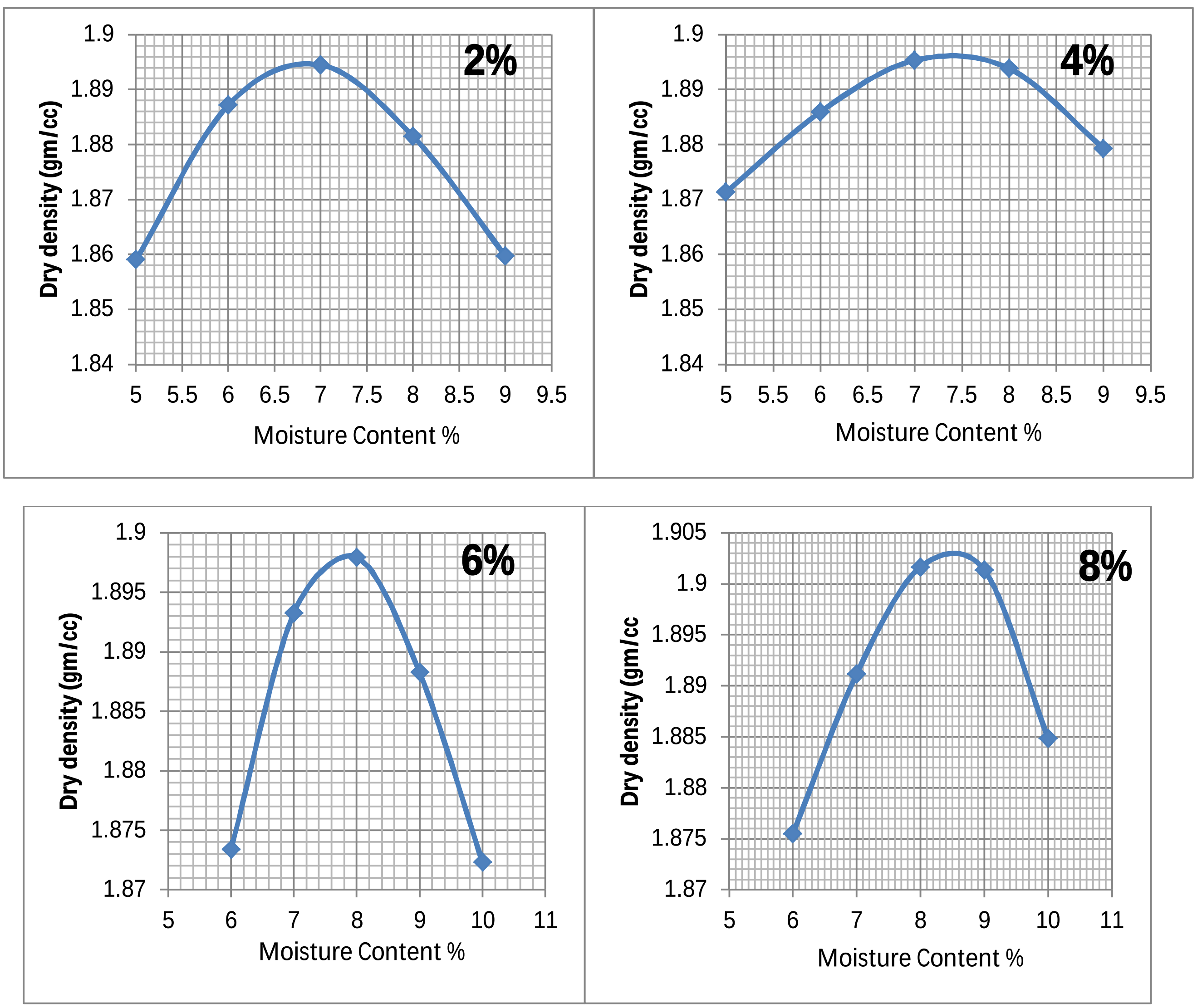

Fig- 2: Graph of compaction test for PA_{10} mixes at different cement content

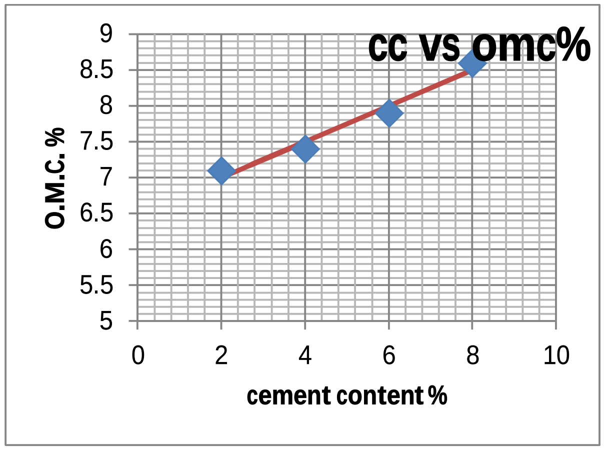

Fig- 3 : Graph between cement content and respective O.M.C.

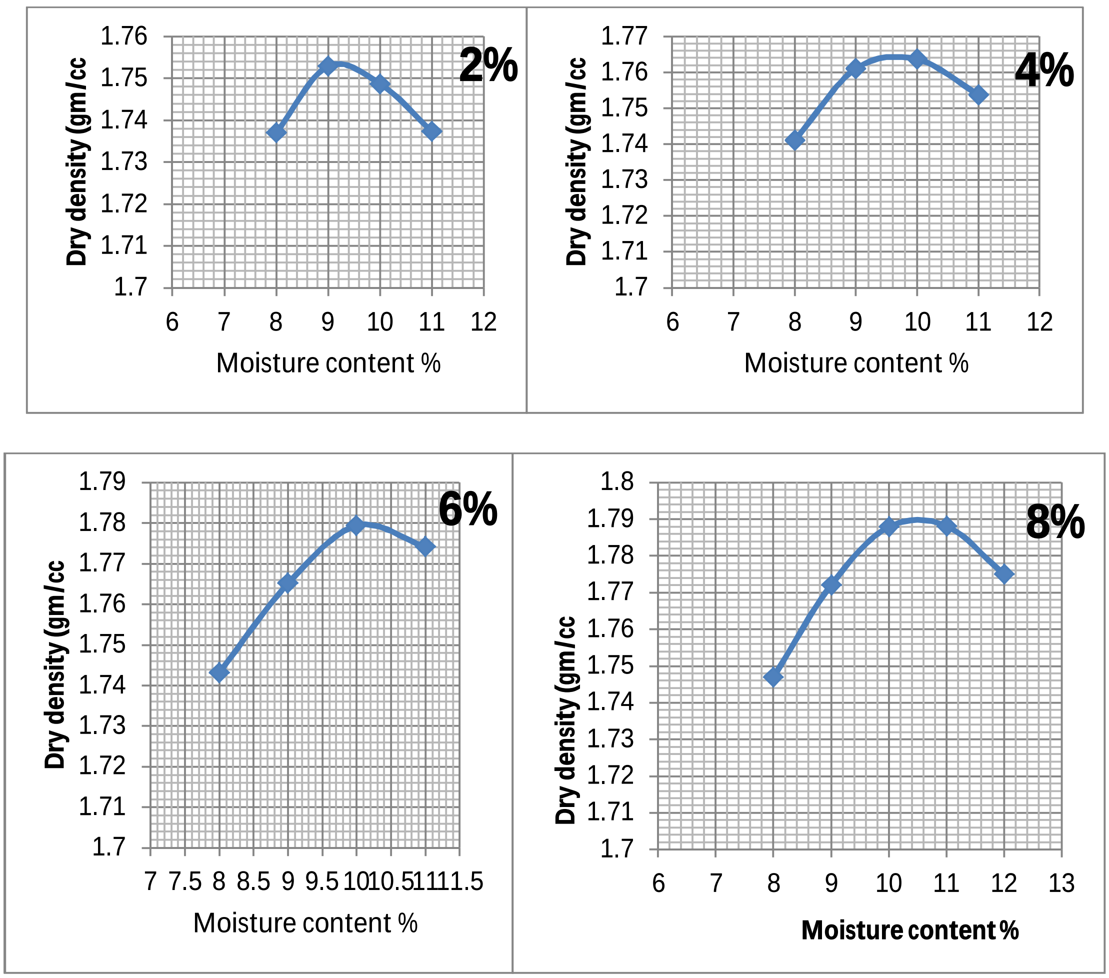

Fig- 4: Graph of compaction test for PA_{20} mixes different cement content

E. CBR method

The samples are prepared by mixing 50% RCA-I, RCA-II (40% and 30%) and pond ash (10% and 20%) by weight. California Bearing Ratio tests, both soaked and unsoaked are conducted. The optimum cement content which gives unconfined compressive strength (UCS) of 17.5kg/cm^2 is selected for the CBR test. As per Highway Material and Pavement Testing Manual by Khanna & Justo (2012), 17.5kg/cm^2 is the minimum compressive strength requirements for base/sub-base course of pavement in case of soil-cement mix. So, the CBR test at two levels of pond ash i.e. PA_{10} and PA_{20} are selected from UCS test results

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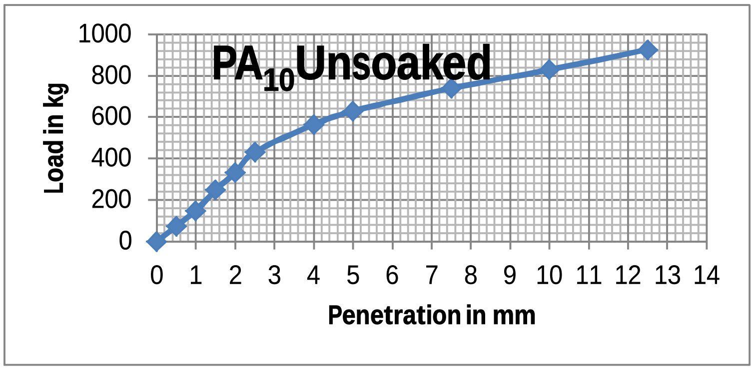
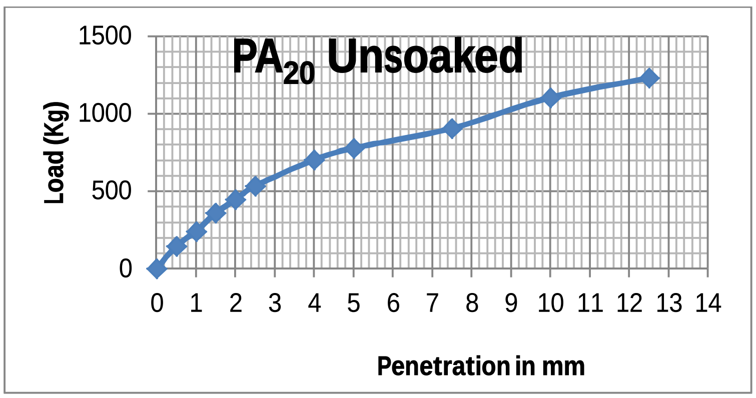
Table 4

S.NO.	Soil Mix- RCA-I : RCA-II : Pond Ash	Cement content	Unsoaked CBR Value (%)	Soaked CBR Value (%)
1	50:40:10	6.50 %	31.04	22.11
2	50:30:20	5.25%	38.41	26.16

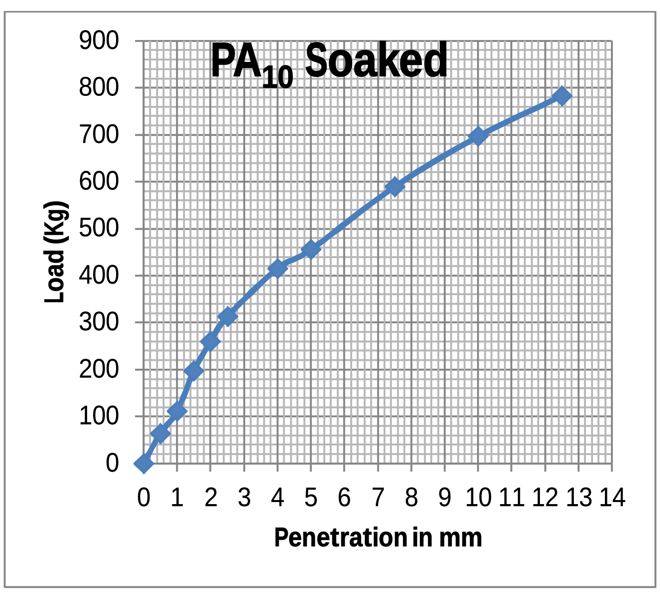


(a)



(b)

Fig-5 (a and b): Graph of unsoaked condition CBR test



(a)

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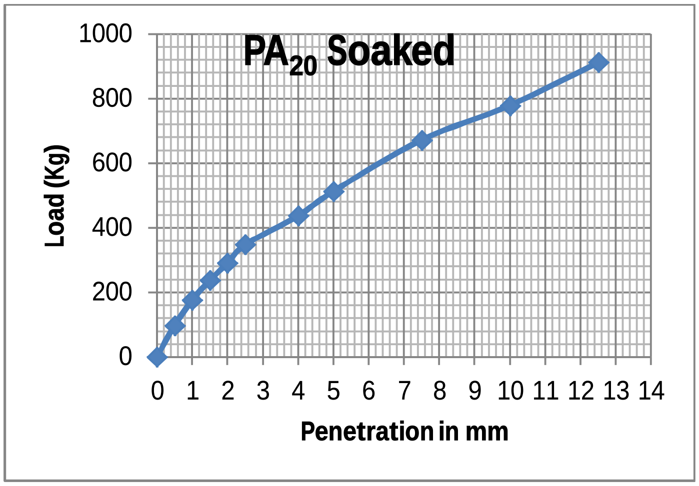

(b)

Fig- 6 (a and b): Graph of soaked condition CBR test

V. ANALYSIS OF RESULTS

A. Optimum moisture content and maximum dry density

The test results in Table 5.1 indicate for the mixes of RCA-I, RCA-II, Pond Ashand cement. The optimum moisture content increases with increase in cement content and pond ash but the MDD increases with increase in cement content and decreases with increase in pond ash content in the mix. For example the MDD decreases (from 1.894 gm/cc to 1.753 gm/cc) with increase in pond ash level from 10% to 20% at same cement content of 2%.

Table 5: Compaction test for different mixes

S.NO.	Soil Mix- RCA-I : RCA-II : Pond Ash	Cement content	MDD (gm/cc)	OMC (%)
1	50:40:10	2 %	1.894	7.1
2	50:40:10	4 %	1.895	7.4
3	50:40:10	6 %	1.897	7.9
4	50:40:10	8 %	1.903	8.6
5	50:30:20	2 %	1.753	9.1
6	50:30:20	4 %	1.767	9.6
7	50:30:20	6 %	1.781	10.1
8	50:30:20	8 %	1.790	10.5

The decrease in dry density of soil by addition of Pond ash may be due to low specific gravity (Density low) of Pond ash. The variation of O.M.C. and maximum dry density with varying percentage of coal ash is depicted in Figs. 7 and 8.

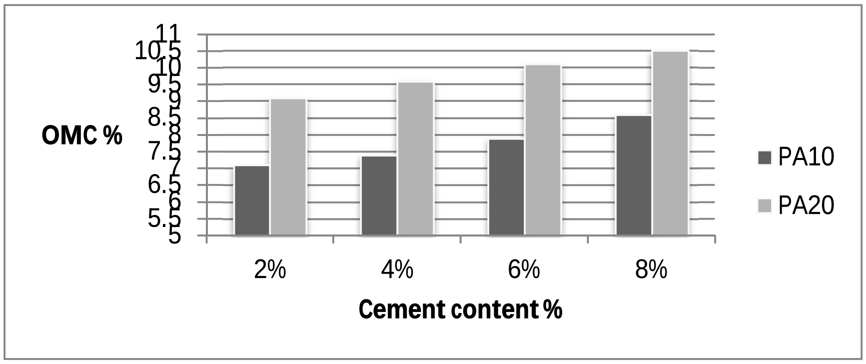

Fig. 7 : O.M.C. of PA_{10} and PA_{20} mixes at different cement content

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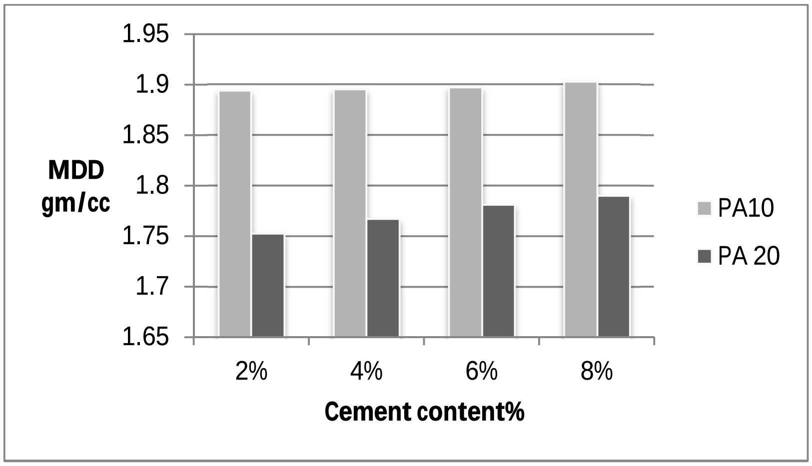

Fig. 8 : MDD of PA_{10} and PA_{20} mixes at different cement content

B. *Unconfined Compressive Strength*

Unconfined compressive strength is an important parameter in pavement design. By the British standards which are also used for Indian conditions, a compressive strength of soil cement mixes equal to 17.5 kg/cm^2 at 7 days curing is considered to be satisfactory for use in sub-base or base course of road pavements in light and medium traffic and under normal climatic condition.

Table 6: UCS Test for different mixes

S.No.	Soil Mix- RCA-I : RCA-II : Pond Ash	Cement content	Unconfined Compressive Strength (kg/cm^2)
1	50:40:10	2 %	9.228
2	50:40:10	4 %	12.11
3	50:40:10	6 %	16.726
4	50:40:10	8 %	19.61
5	50:30:20	2 %	12.112
6	50:30:20	4 %	15.57
7	50:30:20	6 %	19.03
8	50:30:20	8 %	20.763

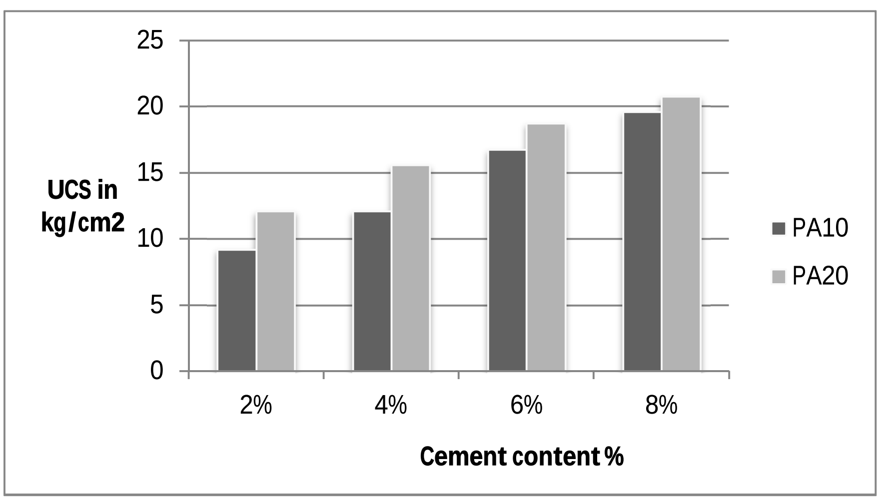

Fig. 9: UCS strength of PA_{10} and PA_{20} mixes at different cement content

Fig. 9 shows the comparison of UCS strength of PA_{10} and PA_{20} mixes at different cement content. It clearly shows that the UCS strength increases with increase in cement content as well as pond ash content.

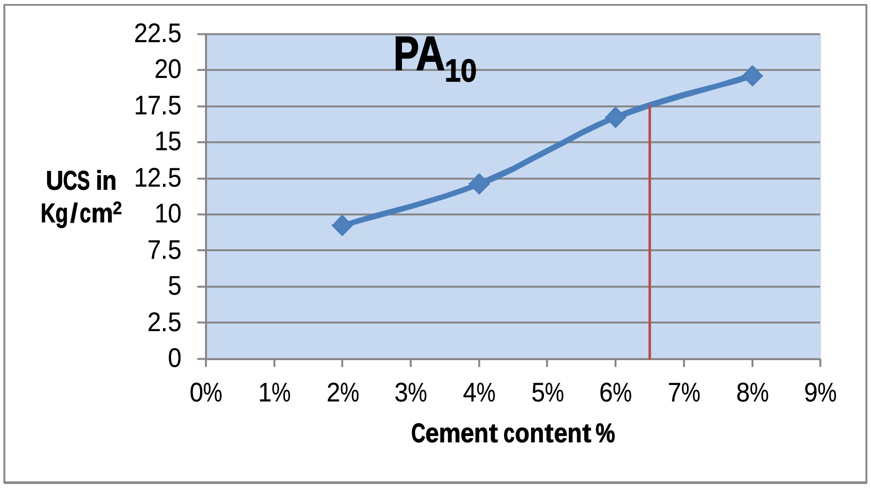

Fig. 10: Graph showing cement content for 17.5 Kg/cm^2 UCS for PA_{10}

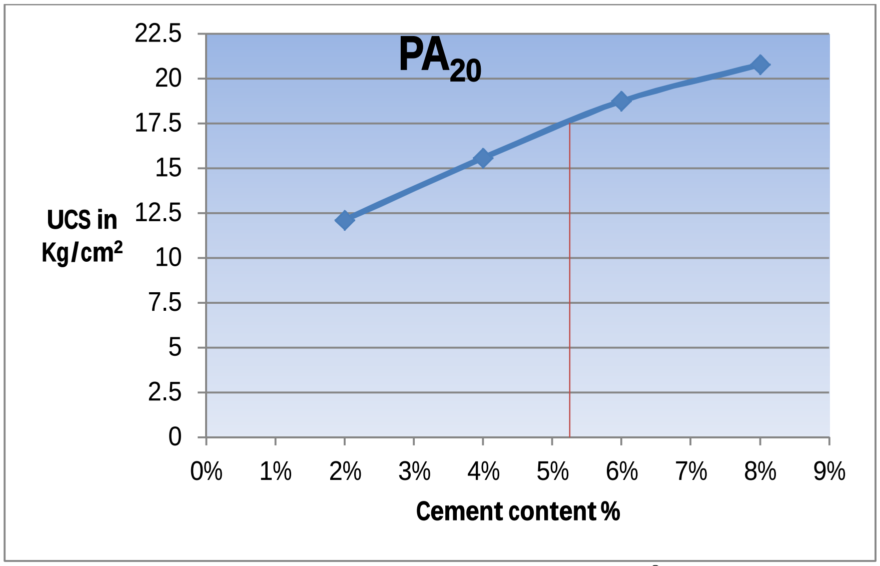

Fig. 11: Graph showing cement content for 17.5 kg/cm^2 UCS for PA_{20}

The Figs. 10 and 11 shows the cement content for average compressive strength of 17.5kg/cm^2. From these graphs it is clear that the mixes PA_{20} with 6.50% of cement content and PA_{20} with 5.25% of cement content give average compressive strength required for sub-base or base course in pavement. So it can be concluded from graphs that 6.50 and 5.25% are optimum cement content for PA_{10} and PA_{20} respectively.

C. C.B.R test

The optimum cement content is determined from UCS test in section 5.2. Table 7 shows the proportion of RCA-I, RCA-II andpond Ashin PA_{10} and PA $_{20}$ mixes and their respective unsoaked and soaked CBR value for the mixes. It is clear that PA_{20} mix has higher CBR value of 26.16% as compare to PA_{10} (22.11% CBR value).

Table 7: CBR test results

S.NO.	Mix- RCA-I : RCA-II : Pond Ash	Optimum Cement content	Unsoaked CBR Value (%)	Soaked CBR Value (%)
1	PA_{10} (50:40:10)	6.50 %	31.04	22.11
2	PA_{20} (50:30:20)	5.25%	38.41	26.16

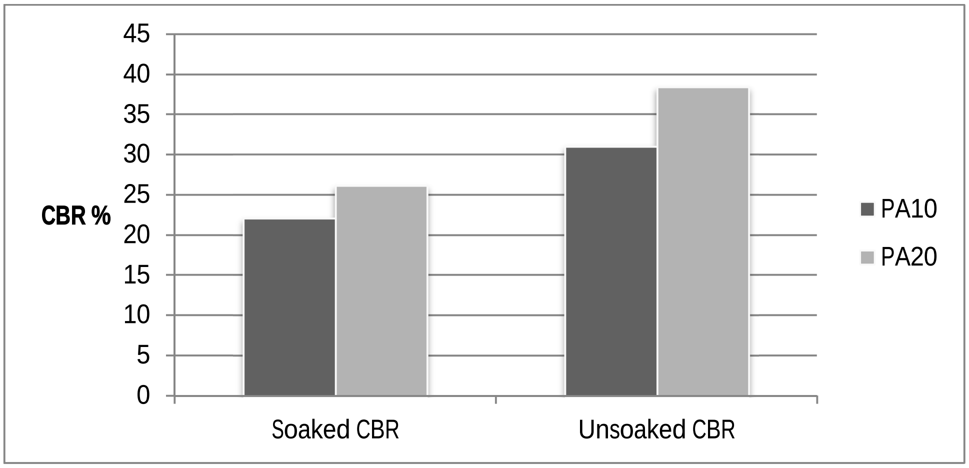

Fig. 12: Soaked and unsoaked CBR values of FA_{10} and FA_{20}

The slump value of all the mixture are represented in Table 8

The slump value v/s percentage of replacement was shown in Table 8. The slump decreased when a higher amount of RHA, WPSA and combination of both (RHA+WPSA) was mix was added in concrete

Table 8: Slump Tests Results

Mix	Percentage	SlumpValue
Control	0%	90mm
RHA	5%	65mm
	10%	55mm
	15%	25mm
	20%	20mm
WPSA	5%	60mm
	10%	55mm
	15%	50mm
	20%	20mm
Mix (RHA+WPSA)	5%	30mm
	10%	20mm
	15%	15mm
	20%	7mm

VI. CONCLUSIONS & RECOMMADATIONS

RCA is a demolition waste which could be utilized with admixtures pond ash and cement in sub-base course of rural road pavements. The present study has shown quite encouraging results and following important conclusions and recommendations can be drawn from the study:

A. The OMC of mixturePA_{10}(50% RCA-I, 20% RCA-II, 10% Pond ash) and PA_{20}(50% RCA-I, 30% RCA-II, 20% Pond ash) increases with increasing the percentage of pond ash. The maximum dry density (MDD) is observed to decrease with increase in the percentage of pond ash.
B. The optimum moisture content (OMC) of RCA-pondash-cement mix increases with increase in cement content of the mix and the increase is linear with increase in cement content.
C. The Unconfined Compression Strength increases with increase in Pond ash from 10% to 20% (i.e. from PA_{10} to PA_{20} mix) in mix for same cement content.
D. The mix with 50% RCA-I (retained on 4.75 mm IS sieve), 30% RCA-II (passing through 4.75 mm IS sieve), 20% Pond ash and 5.25% cement content which gives maximum 26.16% soaked CBR strength.

E. It can be concluded from the analysis of cost of Rural Road that there is decrease in cost of pavement upto 50kms lead for 3% CBR sub-grade and upto 50 kms lead for 5% CBR sub-grade by replacing Moorum with a mix of 50% RCA-I, 30% RCA-II, 20% Pond ash and 5.25% cement. Hence, this proportion may be economically used in road.

F. The cost analysis shows that the difference cost of construction on RCA sub-base and moorum sub-base is marginal up to a lead to 100kms and beyond 100 kms the increase is not so significant that the indirect benefits of using RCA sub-base can be ignored. So, having the indirect advantages of using RCA sub-base which can't be measured in terms of cost, the RCA sub-base can be used with marginal increase in direct cost.

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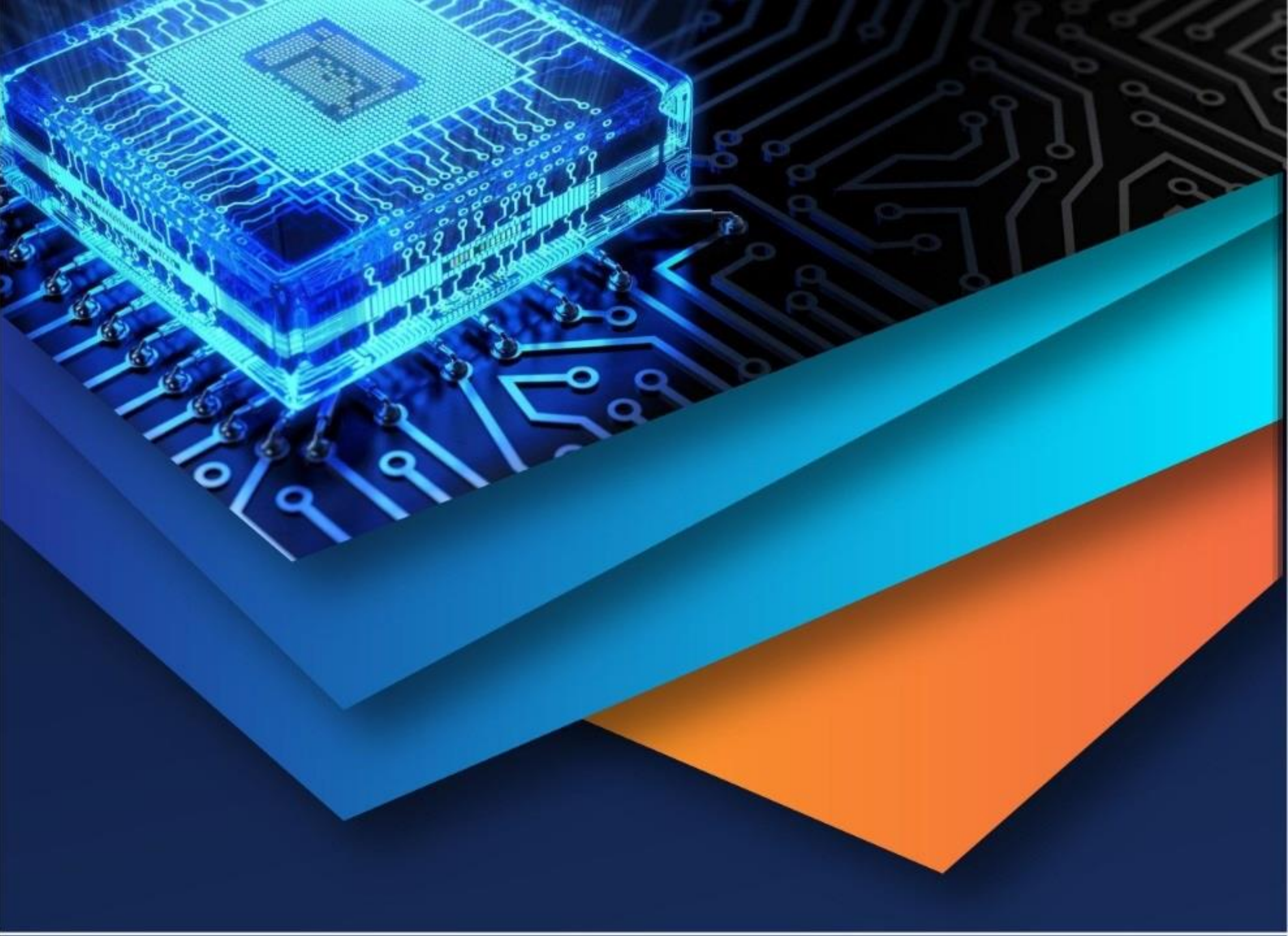

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