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"Effect Of Optimized Triple Mix Approach On The Properties Of RAP Inclusive Concrete"

[1]Ranera puja,[2]Bonny Bhut, [3]Shekhar Parmar

[1]Student of M.Trech(Transportation), [2]Prof. of M.Tech Transportation, [3]Prof. of M.Tech Transportation
[1]Transportation Engineering,
[1]Dr. Subhash Technical Campus,Junagadh,India

Abstract**—** This study examines the effect of using an "optimized triple mix" (OTM) on the properties of recycled asphalt pavement (RAP) aggregate concrete (RAPC) and "Abrasion and Attrition" (ABTRAP) aggregate concrete (ABTRAPC). The OTM approach involves coating the RAP aggregate with pozzolanic materials to reduce porosity and increase the C-S-H content, which improves the interfacial transition zone (ITZ). In both RAPC and ABTRAPC mixes, 10% of ordinary Portland cement (OPC) is replaced with silica fume. The laboratory tests showed that the OTM approach improved the compressive strength, flexural strength, and split tensile strength of RAPC and ABTRAPC mixes compared to the standard mix approach. The 50ABTRAPC mix prepared by the OTM approach exhibited better compressive strength, flexural strength, and split tensile strength than natural aggregate concrete (NAC). The cost analysis revealed that the 100ABTRAPC mix cost per 1 m3 of concrete was 9.793% less than NAC.

Keywords- Recycled Asphalt Pavement (RAP); Recycled Asphalt Pavement Aggregate Concrete(RAPC), RAP Aggregate Treated by Abrasion & Attrition Technique" (ABTRAP), ABTRAP Aggregate Concrete Containing 10% Silica Fume – (ABTRAPC)

I. Introduction (Heading 1)

Give me ideas for improvement" In India, two types of pavement are laid i.e. flexible pavement and rigid pavement. The type of pavement for national highway projects is adopted based on durability and life cycle project cost. Based on the life cycle cost analysis studies on pavements, it was found that the initial cost of construction of cement concrete pavement is higher than flexible pavements, but the overall life cycle cost of rigid pavement is low compared to flexible pavement. Considering the issues related to long-term durability, longer service life, less fuel consumption, resistance to extreme weather conditions, saving natural resources and maintenance, etc., the cement concrete pavement could be the default mode of construction of national highways (Committee on Public Undertakings, 2017-18).

Rigid pavements are high-stiffness pavements with a main structural layer of cement concrete. The cement concrete layer is considered the heart of rigid pavement because the performance of pavement mainly depends upon the concrete performance. Concrete is a composite material composed of fine aggregate; coarse aggregate is bonded together with a cement paste that hardens (cures) over time. According to Abram's law, the strength of concrete depends on the water-cement ratio. The strength of concrete is inversely proportional to the mass ratio of water to cement. The interfacial transition zone properties of concrete also mainly influence the mechanical properties of concrete (Brand & Roesler, 2017a). This is the region of about 50μm thick surrounding the aggregate. Generally, the strength of concrete is expressed in terms of characteristic compressive strength or flexural strength. For low-volume, (less than 450 CVPD) and high-volume traffic (greater than 450 CVPD) concrete pavement recommends flexural strength of concrete of at least 3.6 Mpa and 4.5 Mpa respectively (IRC 58-2015).

Typical concrete pavement consists of different layers such as embankment, subgrade, sub-base/base layer, DLC layer, and cement concrete layer. Each layer of construction requires a large quantity of aggregates i.e. natural aggregates or marginal aggregates. Conventional construction practice uses natural aggregates. Natural aggregate consists of manufactured crushed stone and sand created by crushing bedrock or naturally occurring unconsolidated sand and gravel (Langer, 2016). The marginal aggregates such as reclaimed asphalt pavement (RAP) aggregates, recycled concrete aggregates, steel slag aggregates, etc., will not have the characteristics required by the specification i.e. lower in quality. Generally, marginal aggregates were used in an embankment, subgrade, sub-base/base layers, dry lean concrete layer, or shoulders because these layers carry low stresses compared to the top structural layer. The usage of marginal aggregates in the cement concrete layer produced inferior properties that would affect the structural and functional performance of the pavement. However, processing the marginal aggregates could improve the quality that might be used in the cement concrete layer.

Reclaimed asphalt pavement (RAP) is the term given to removed and/or reprocessed pavement materials containing asphalt and aggregates (FHWA Report, 2017). These materials are generated during milling (controlled or uncontrolled) of (Farina, et al., 2017). Controlled Milling is the controlled removal of an existing pavement to the desired depth, using specially designed equipment. It is the most common way of reclaiming bituminous pavement material. RAP can also be obtained from the demolition of flexible pavement using a bulldozer or backhoe, known as uncontrolled milling (IRC: 120-2015). After milling of asphalt pavements, on-spot utilization of RAP material for the rehabilitation of flexible pavement at the project site can be done using a train of equipment or it can be stockpiled at a recycling plant, or it can be disposed of at the landfill (IRC: 120-2015).

Audrey Copeland (2011) recommends that RAP is a useful alternative to virgin materials because it reduces the usage of virgin aggregates when RAP is used in the pavement layers substitute to natural aggregates. Particularly, when RAP is used in the surface course or binder course of flexible pavement it reduces both virgin asphalt binder and the aggregate requirement to produce hot mix asphalt (HMA). Usage of RAP also conserves the energy lowers transportation costs required to obtain the virgin aggregate and preserves resources. The use of RAP aggregate in the construction of pavement layers and shoulders also reduces the burden on landfills.

RAP material consists of asphalt film around aggregate. Asphalt film gets stiffened by aging due to the oxidation process (De lira, et al., 2015). This stiff asphalt film has to be softened by using rejuvenators when we use it in bituminous mixes, but it is an advantage for cement concrete mixes which may create a better bond between stiff asphalt film and cement matrix compared to soft asphalt film and cement matrix. RAP is stockpiled after milling while in the stockpile stiffening of asphalt film is accelerated and dust layers (stiff and loose) are formed adhering to the asphalt films. Therefore, the presence of dust, asphalt film, and agglomerated particles is the primary reason for reducing the properties of RAP-inclusive concrete compared to natural aggregate concrete (S. Singh, et al., 2017a).

II.Abbreviations and Acronyms

AB & AT – Abrasion and Attrition
ABTRAP – RAP Aggregate Treated by Abrasion & Attrition Technique
ABTRAPC – ABTRAP Aggregate Concrete Containing 10% Silica Fume
C-S-H – Calcium Silicate Hydrate
ITZ – Interfacial Transition Zone
NAC – Natural Aggregate Concrete
OTM – Optimized Triple Mix
RAP – Reclaimed Asphalt Pavement
RAPC – RAP Aggregate Concrete Containing 10% Silica Fume
RAP - PCC – Reclaimed Asphalt Pavement in Portland Cement Concrete
SP – Super Plasticizer
SF – Silica Fume
TM – Triple mix

III. Methodology

a) Sieving

The Rap Material That Was Collected Underwent A Process Of Sieving In The Lab To Separate It Into Two Categories: Fine Rap (< 4.75mm) And Coarse Rap (> 4.75 Mm). However, We Chose Not To Use Fine Rap In Our Study Due To The Following Reasons:

1. According To The Literature, Incorporating Fine Rap In Concrete Could Lead To A Significant Decline In The Mechanical (Compressive Strength, Flexural, And Split Tensile Strength) And Durability Properties Of Concrete Because Of Its Gap Gradation, Dust Content, And The Presence Of More Agglomerated Particles In The Fine Rap (Singh Et Al., 2018a).

2. Fine Rap Contains A Higher Quantity Of Asphalt, Which Can Be Used More Economically For Hma Mixtures.

b) Abrasion And Attrition Technique

In This Study, A Technique Called "Abrasion & Attrition" Is Used To Process A Fractioned Coarse Rap Sample (Singh Et Al., 2017a).

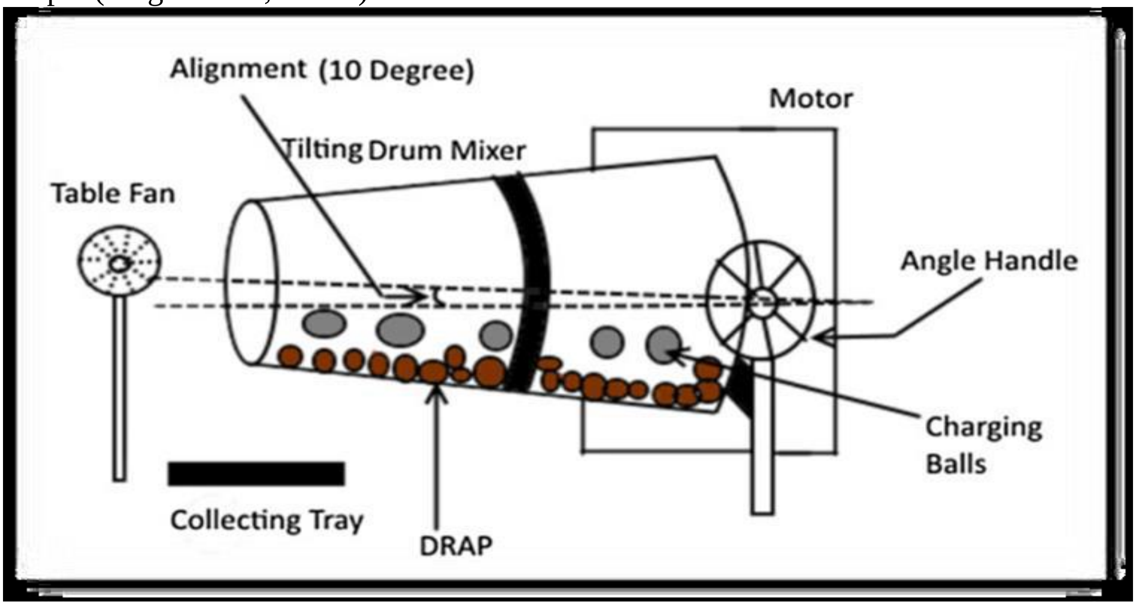


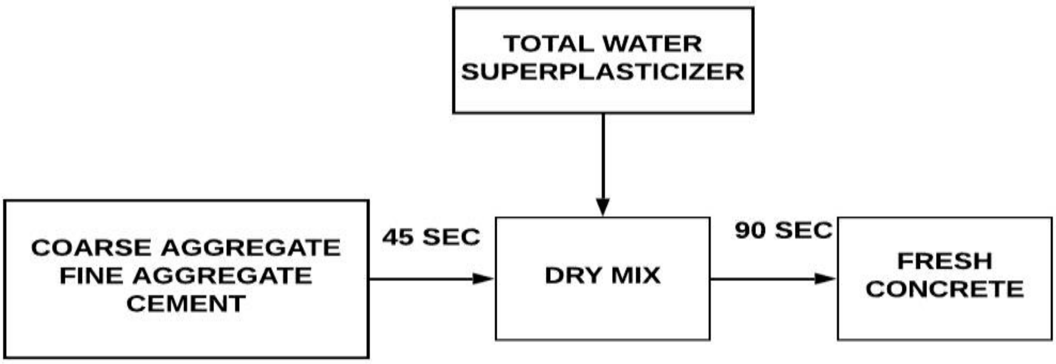
Figure 1 Abrasion & Attrition Setup.

About 25kg Of Rap Aggregates Are Added To A Tilt Drum Mixer, Along With 15 Abrasive Charge Balls. The Charge Balls Have An Average Diameter Of 4.5 Cm And An Average Weight Of 380 Gm. The Mixer Is Rotated At 35 Rpm For 15 Minutes, And The Resulting Sample Is Then Sieved Through A 4.75 Mm Sieve.

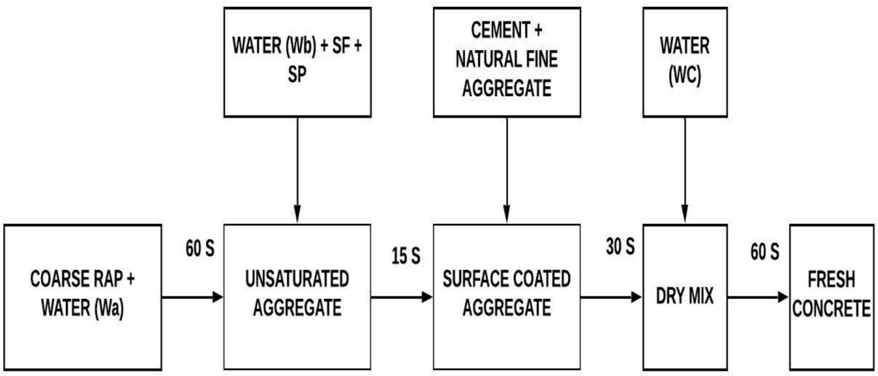
The Literature Suggests That Replacing 10% Of Opc With Silica Fume Improves The Mechanical And Durability Properties Of Abtrap-Inclusive Concrete (Singh Et Al., 2017b). According To Irc:44-2017, Silica Fume Can Be Used Up To 10% Of The Cementitious Materials For Concrete Pavement Construction. Therefore, 10% Silica Fume By Weight Of Cement Is Used In This Study. The Addition Of Silica Fume Increases The Stiffness Of The Concrete Mix Due To The High Specific Surface Area Particles. As A Result, A Chemical Admixture Is Used To Improve The Workability Of The Concrete.

c) Mix Approach

Previous Studies Have Explored Different Approaches To Improve The Microstructure Of Recycled Aggregate Concrete. These Approaches Include Double Mix, Triple Mix, And Optimized Triple Mix. The Common Mechanism Between These Mixed Approaches Is The Surface Coating Of Cementations Material Around The Surface Of The Aggregate. This Surface Coating Helps To Consume C-H Crystals Present In The Pores And Cracks Around The Recycled Aggregate And Form C-S-H Gel During The Second Hydration Activity. The "Optimized Triple Mix" Approach Has Been Found To Significantly Improve The Properties Of Recycled Aggregate Concrete. Therefore, In This Study, The "Optimized Triple Mix" Approach Is Used To Improve The Mechanical Properties Of Rap-Pcc (Reclaimed Asphalt Pavement Aggregates With Asphalt Film Around The Aggregate). The Results Will Be Compared With The Normal Mixing Method, Which Is Shown In Figure 3.1.



(A) Normal Mix Method.



(B) Optimized Triple Mix Method.

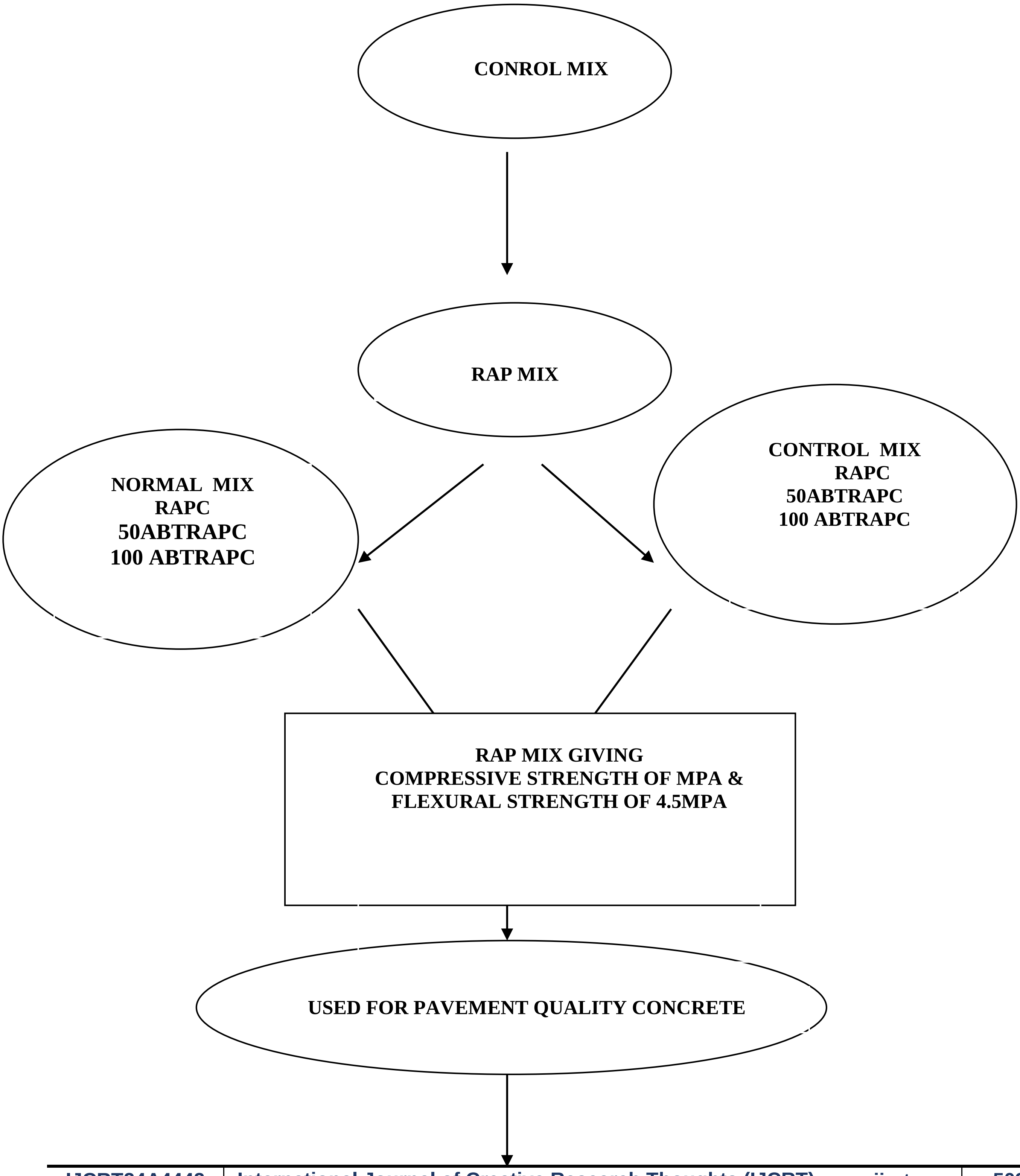
Figure. 2 Comparison Of Mixing Methods.

d) Experimental Program

In This Study, Four Different Concrete Mixes Were Designed And Tested. The First Mix Was A Control Mix That Contained 100% Natural Coarse And Fine Aggregates. The Second Mix Was Made With Recycled Asphalt Pavement (Rap) Aggregates. The Third Mix, Called Rapc, Replaced 100% Of The Natural Coarse Aggregates With Coarse Rap Aggregates And Used 10% Silica Fume To Replace Opc. The Last Two Mixes, Known As Abtrap, Used Abtrap Coarse Aggregates To Replace 50% And 100% Of The Natural Coarse Aggregates, Respectively, And Also Utilized 10% Silica Fume To Replace Opc.

Two Approaches Were Used To Prepare The Concrete Mix: The Normal Mix Approach And The Optimized Triple Mix Approach. The Mechanical Properties Of The Concrete Specimens Prepared By Both Approaches Were Analyzed And Compared. Additionally, The Cost Of The Rap-Inclusive Concrete Mixes Per 1 M3 Of Concrete Was Analyzed And Compared To That Of The Natural Aggregate Concrete.

To Help Visualize The Methodology, A Flow Chart Was Provided In Figure 3.3.



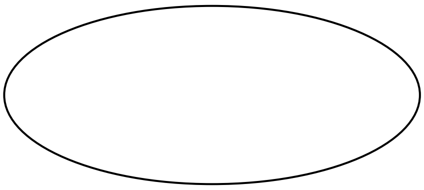


Figure 3 Methodology Flow Char

IV. Results and Calculations

a) Fresh Properties of Concrete

The slump values of considered mixes under normal mix method and optimized triple mix method are shown in table 5.1

Table 1 Slump Values of Considered Mixes

Slump Value(mm)		
Mixes	**Normal mix**	**Optimized triple mix**
NAC	45	-
100RAPC	18	24
50ABTRAPC	42	46
100ABTRAPC	38	43

The slump values of RAPC, 50ABTRAPC, and 100ABTRAPC mixed by optimized triple mix method were increased compared to the normal mix method. It was hypothesized that the surface coating of aggregate with silica fume at low water content along with superplasticizer provides more water available to achieve workability. The slump value of RAPC was increased by 33.33% compared to the normal mix method. The slump values of 50ABTRAPC and 100ABTRAPC were increased by 15.78% and 11.9% compared to the normal mix method respectively. The slump value of 50ABTRAPC observed greater than the NAC

b) Compressive Strength of Concrete

The 7-day and 28-day compressive strength values of considered mixes are shown in table 5.2 and table 5.3 respectively. The compressive strength values in the table are the average of three specimens.

Table 2 7-Day Compressive Strength of Considered Mixes

7-dayCompressivestrength (Mpa)		
Mixes	**Normal mix method**	**Optimized triple mix**
NAC	34.7	-
RAPC	23.6	26.1
50ABTRAPC	35.3	37.42
100ABTRAPC	32.5	34.4

Table 3 28-Day Compressive Strength of Considered Mixes

28-dayCompressivestrength(Mpa)		
Mixes	**Normal mix method**	**Optimized triple mix**
NAC	47.7	-
RAPC	32.5	36.4
50ABTRAPC	48.32	50.2
100ABTRAPC	46.21	48.4

From table 5.1 and 5.2, the compressive strength values of RAPC, 50ABTRAPC, and 100ABTRAPC mixed by optimized triple mix method were increased compared to the normal mix method. Comparison graphs of optimized and normal mix methods of considered mixes are shown in figures 5.1 and 5.2. From figure 5.1, the results showed that 7-day compressive strength values of RAPC, 50ABTRAPC, and 100ABTRAPC mixed by optimized triple mix were increased by 10.59%, 6%, and 5.8% compared to the normal mix method respectively. From figure 5.2, the results showed that the 28-day compressive strength values of RAPC, 50ABTRAPC, and 100ABTRAPC mixed by optimized triple mix were increased by 12%, 3.89%, and, 4.73% compared to the normal mix method respectively. Both 7-day and 28-day compressive strength values of 50ABTRAPC mix prepared by OTM and normal mix found greater than the NA

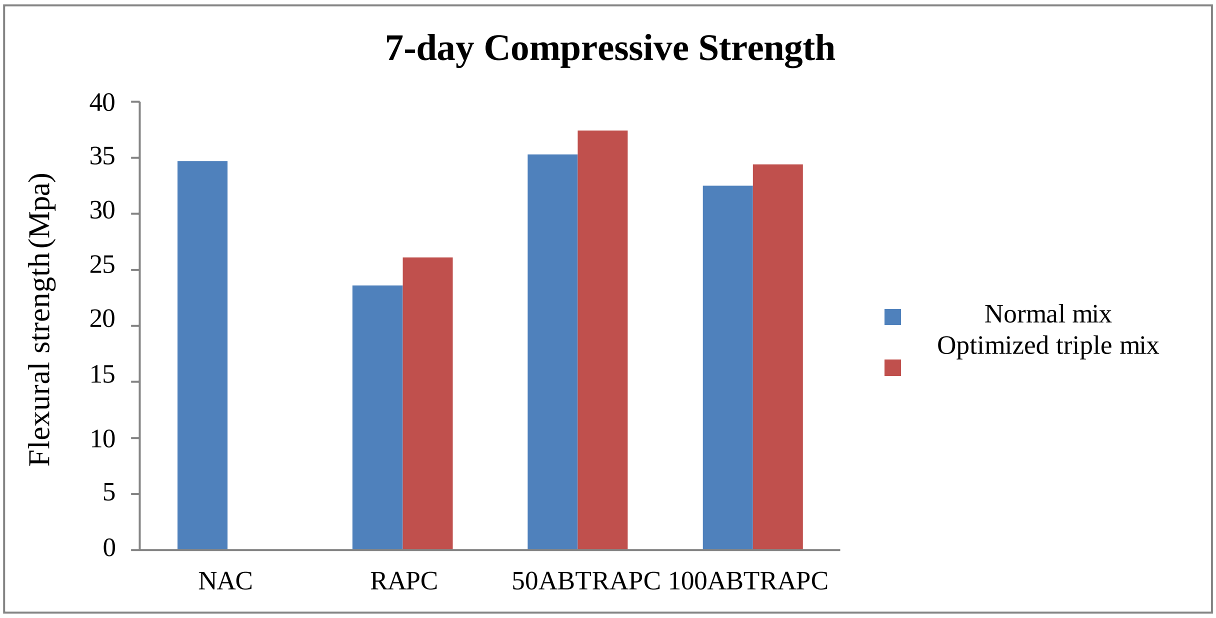


Figure 5 Effect of Mix Approach on the 7-DayCompressive Strength

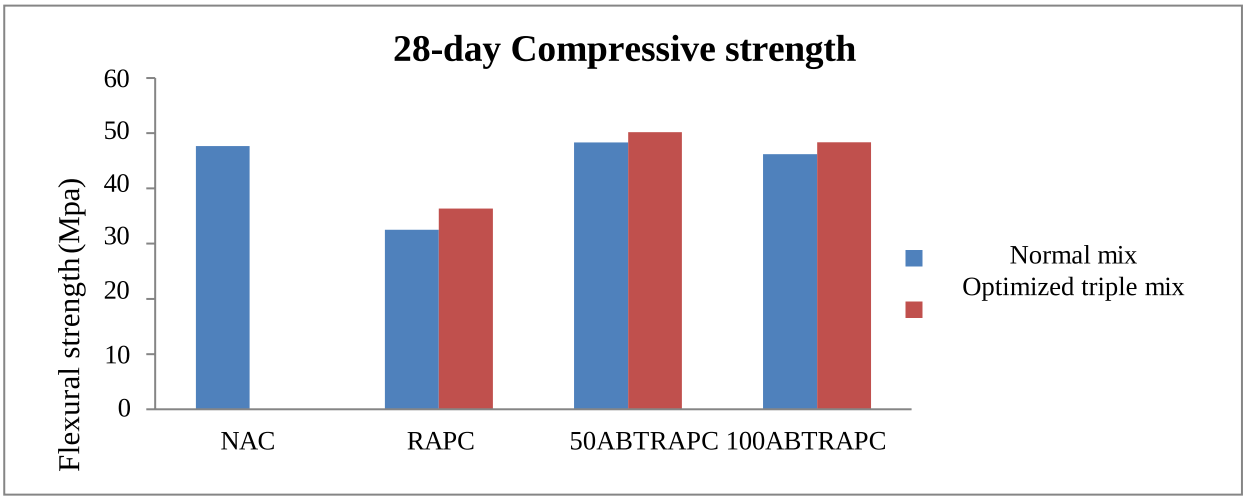


Figure 6 Effect of Mix Approach on the28-Day Compressive Strength

c) Flexural Strength of Concrete

The 7-day and 28-day flexural strength values of all considered mixes are shown in table 5.3 and table 5.4 respectively. The flexural strength values in the table are the average of two specimens

Table 4 7-day Flexural Strength of Considered Mixes.

Flexural strength(Mpa)		
Mixes	**Normal mix method**	**Optimized triple mix**
NAC	4.1	-
RAPC	3.65	3.9
50ABTRAPC	4.2	4.42
100ABTRAPC	4.04	4.27

Table 5. 28-DayFlexural Strength of Considered Mixes.

Flexural strength(Mpa)		
Mixes	**Normal mix method**	**Optimized triple mix**
NAC	5.95	-
RAPC	4.52	4.77
50ABTRAPC	5.8	6.04
100ABTRAPC	5.45	5.72

The flexural strength of concrete is also increased same as compressive strength when the mix proportions mixed by optimized triple mix approach compared to the normal mix approach. Comparison graphs of optimized and normal mix method for all considered mixes are in figure 5.3 and 5.4. From figure 5.3, the results showed that 7-day flexural strength values of RAPC, 50ABTRAPC, and 100ABTRAPC mixes prepared by optimized triple mix were increased by 6.84%, 5.23%, and 5.69% compared to the normal mix method respectively. From figure 5.4, it was observed that 28-day flexural strength values of RAPC, 50ABTRAPC, and 100ABTRAPC mixes prepared by optimized triple mix were increased by 5.53%, 4.1%, and 4.95% compared to the normal mix method respectively.

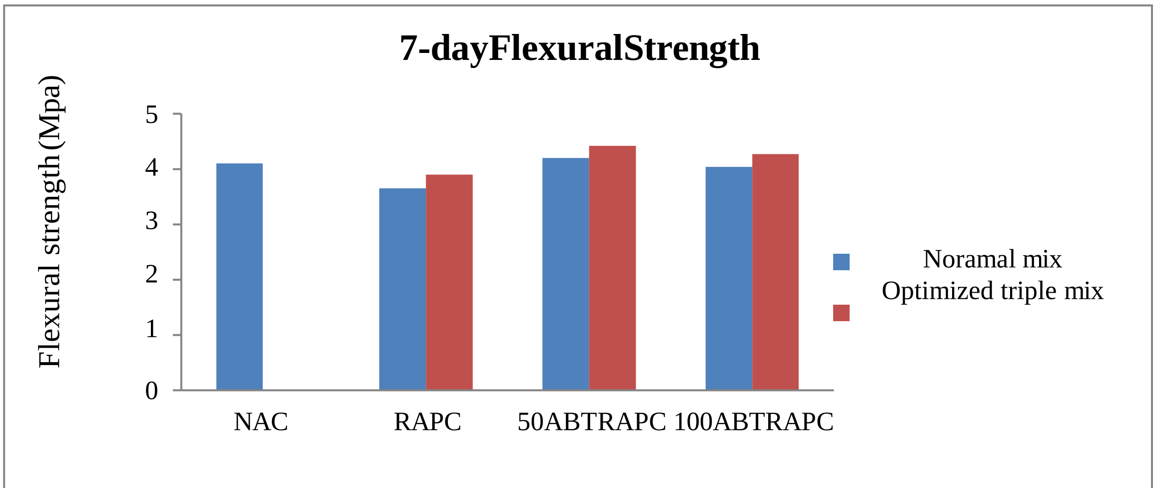


Figure 7 Effect of Mix Approach on the 7-Day Flexural Strength

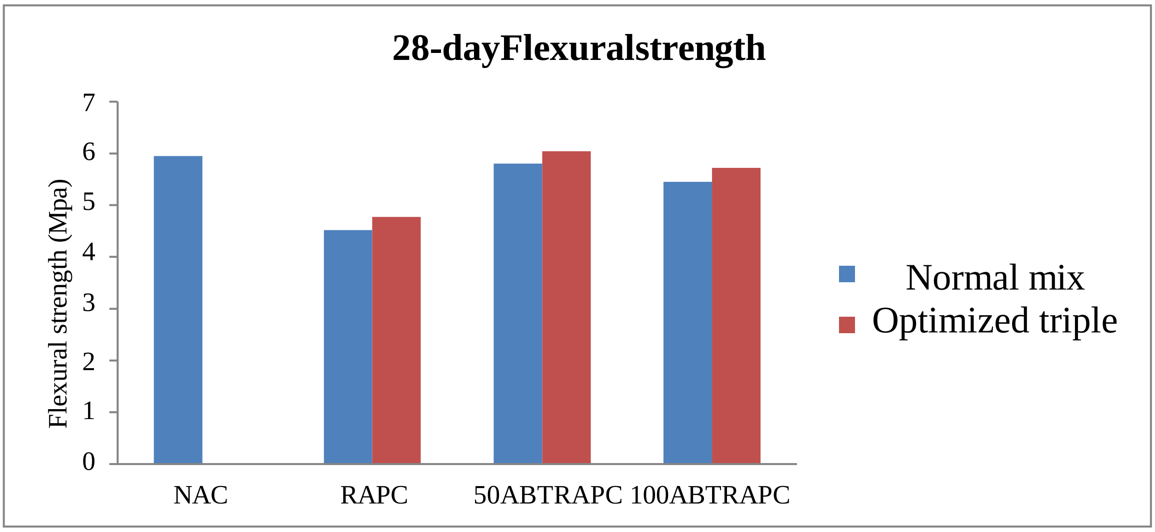


Figure 8 Effect of Mix Approach on the 28-DayFlexural Strength.

Split tensile strength

The 7-day and 28-day split tensile strength values of all considered mixes are shown in table 5.5 and table 5.6 respectively. The split tensile strength values in the table are the average of three specimens.

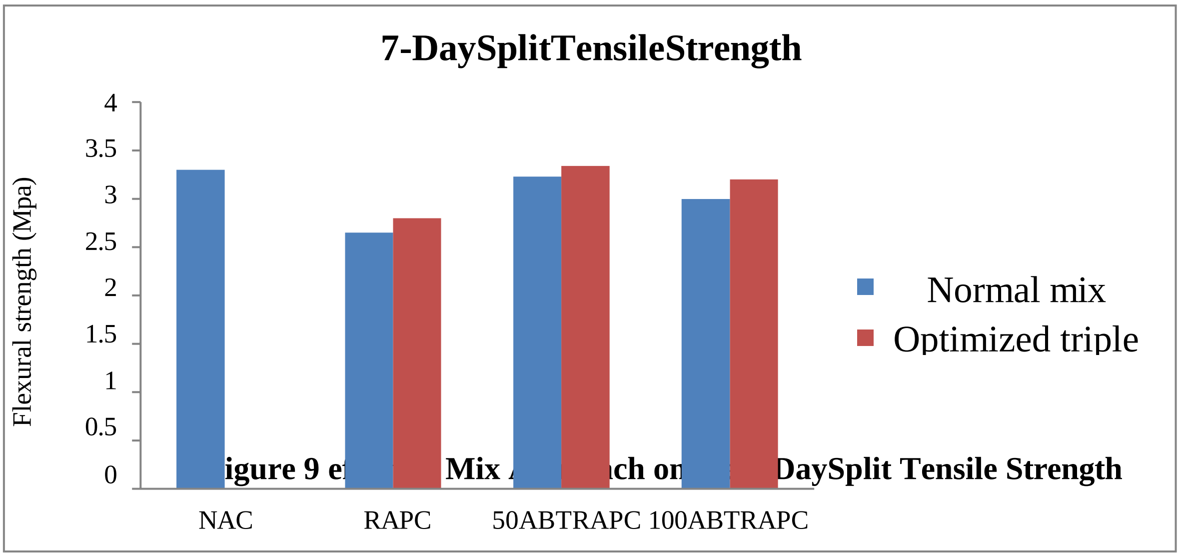
Table 6 7-Day Split Tensile Strength Values of Considered Mixes.

Split tensile strength(Mpa)		
Mixes	**Normal mix method**	**Optimized triple mix**
NAC	3.3	-
RAPC	2.65	2.8
50ABTRAPC	3.23	3.34

100ABTRAPC	3.0	3.2

Table.7 28-DaySplitTensile Strength Values of Considered Mixes.

The split tensile strength of concrete is also increased when the mix proportions mixed by an optimized triple mix approach compared to the normal mix approach. From figure 5.5, the results showed that 7-day split tensile strength values of RAPC, 50ABTRAPC, and 100ABTRAPC mixed by optimized triple mix were increased by 5.67%, 3.4%, and 6.67% compared to the normal mix method respectively. From figure 5.6, the results shows that 28-day split tensile strength values of RAPC, 50ABTRAPC, and 100ABTRAPC prepared by optimized triple mix were increased by 8.88%, 3.13%%, and 2.54% compared to the normal mix method respective



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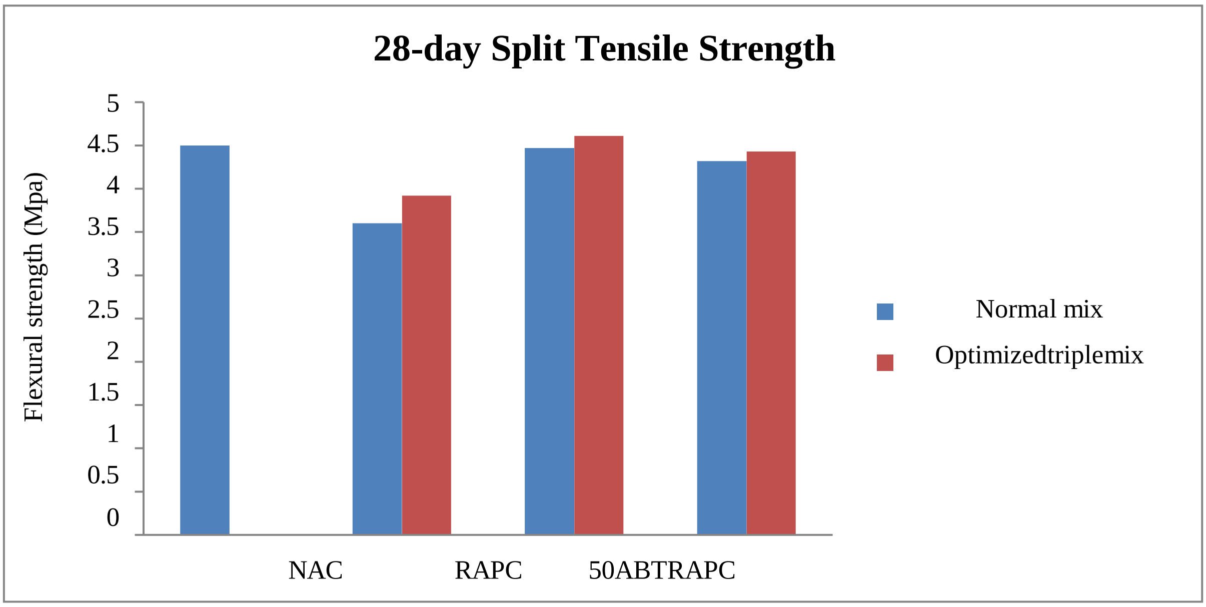

Split tensile strength(Mpa)		
Mixes	**Normal mix method**	**Optimized triple mix**
NAC	4.5	-
RAPC	3.6	3.92
50ABTRAPC	4.47	4.61
100ABTRAPC	4.32	4.43

Figure 10. Effect of Mix Approach on the 28-Day Split Tensile Strength.

V. CONCLUSION

Based on the laboratory investigation results, it was found that the workability of mixes prepared by the OTM approach is better than the normal mix approach. This is due to the surface coating of aggregate with silica fume at low water content along with superplasticizer, which provides more water to achieve workability.

The optimized triple mix approach increased the compressive strength of RAC, 50 ABTRPAC, and 100 ABTRAPC by 12%, 3.89%, and 4.73%, respectively, compared to the normal mix method at 28 days of curing. This is because the surface coating of the aggregate with silica fume improved the ITZ properties.

The flexural strength and split tensile strength of the mixes were also increased significantly when prepared with the OTM approach. However, surface coating of ABTRAP aggregate with silica fume did not further improve the ITZ properties, which is why the mechanical properties of ABTRAPC were not improved significantly when a mix was prepared by the OTM approach.

The dispersion of silica fume in the ITZ by the OTM approach reduced the porosity and increased the C-S-H content, which improved the mechanical properties of the RAPC mix prepared by OTM compared to the normal mix approach.

The cost of the 100ABTRAPC mix per 1 m3 of concrete was found to be 9.793% less than the NAC, making it an economical choice. However, the cost of the 50ABTRAPC mix was found to be 6.25% more than the NAC. This increased cost can be compensated by the increase in mechanical properties of the concrete compared to the NAC, particularly when considering the transport of RAP aggregates to the landfill site, landfilling RAP aggregate cost, and lead in km increase.

VI. RECOMMENDATIONS

- For The Construction Of Concrete Pavements, Using Recycled Asphalt Pavement (Rap) Aggregates Without Any Processing In Concrete Results In Inferior Properties. As A Result, Rap Aggregates Need To Be Processed To Enhance The Properties Of Concrete. The Rap Aggregates Can Be Treated Using The "Abrasion And Attrition" Technique (Singh Et Al., 2017a) To Improve The Properties Of Rap Concrete. This Technique Involves Removing The Contamination Dust Layers And Some Patches Of Asphalt Around The Aggregate. However, It Was Found That The Properties Of Concrete Using Rap Aggregates Are Still Less Than Those Using Natural Aggregates. To Further Enhance The Properties Of Abrasion-Treated Rap (Abtrap) Concrete, The Addition Of Silica Fume Has Been Found To Produce Comparable Strength To Natural Aggregate Concrete (Nac). Additionally, Abtrapc Mix Prepared Using The Optimized Triple Mix Approach Exhibits Slightly Greater Strength Than Nac.
- When Constructing Concrete Pavements In Remote Locations Or At A Significant Distance From Quarries Or Project Sites, There Is An Increase In The Transport Cost Of Materials. Using Milled Rap Aggregate In Concrete Pavement Can Significantly Reduce The Transport Cost Of Aggregate And Also

Reduce Rap Disposal Problems. Therefore, Utilizing Rap Aggregate In Concrete Pavements At Such Locations Can Provide An Economical And Environmentally Friendly Output.

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