A Review on Experimental Study of Design of Rigid Pavement by using Recycled Coarse Aggregate with M30 Mix Design

Hemant Kumar Tiwari[1], Anil Kumar Patel[2]

[1]M.Tech. Research Scholar, Department of Civil Engineering, Saraswati Institute of Engineering and Technology, Jabalpur (M.P.), India

[2]Assistant Professor, Department of Civil Engineering, Saraswati Institute of Engineering and Technology, Jabalpur (M.P.), India

[1]hemanttiwari049@gmail.com, [2]patelanil2493@gmail.com

---***---

Abstract – Concrete, a fundamental construction material, boasts attributes like durability, versatility, and cost-effectiveness. However, the depletion of natural resources and the escalating concrete waste production necessitate innovative solutions. In this rapidly industrializing world, recycling construction materials plays a pivotal role in preserving our finite resources.

Concrete pavements, widely practiced in developed countries, are relatively new in India. Selecting the right pavement type is crucial, but equally important is determining the optimal pavement thickness based on traffic levels, subgrade conditions, and environmental factors. Unfortunately, many existing methodologies overlook critical factors (such as vehicle loads, support loss, thermal gradients, and environmental stress), leading to inaccurate thickness calculations.

In this context, rigid pavement construction using recycled coarse aggregate (RCA) emerges as an eco-friendly and cost-effective solution.

In a recent research endeavour, Recycled Coarse Aggregates (RCAs) sourced from demolished material took center stage. These demolished materials are meticulously crushed to a suitable size and repurposed as recycled coarse aggregate. Meanwhile, natural sand continues to serve as the fine aggregate. Notably, the concrete industry consumes a staggering 12.6 billion tons of raw materials annually, making it the world's largest natural resource consumer.

The environmental impact of concrete production—especially the extraction of raw ingredients such as cement, coarse aggregates, and fine aggregates—is considerable. To address this, the study employed a trial-and-error approach for mix design, adhering to relevant standards (such as IS code and IRC: 44-2008). For M30 grade cement concrete, varying percentages (0%, 25%, 50%, 75%, and 100%) of recycled coarse aggregates replaced conventional coarse aggregates. Casting used cube and beam models to obtain laboratory test results for rigid pavement to determine how much optimal percentage of RCA can be substituted in place of NCA.

By integrating RCAs, we not only mitigate environmental impact but also contribute to sustainable rigid pavement structures.

***Key Words*:** Rigid Pavement Design, Recycled Coarse Aggregate, RCA Concrete, Natural Coarse Aggregate, NCA Concrete, Mix Proportion, Pavement Thickness, Life Cycle Cost, And Environmental Benefits etc.

1. INTRODUCTION

Rigid pavement is a type of pavement that has a high flexural strength and can distribute the traffic load over a large area. It is usually made of Portland cement concrete (PCC) and reinforced with steel bars or fibers. Rigid pavement has many advantages such as long service life, low maintenance cost, good skid resistance and high load carrying capacity.

However, rigid pavement also has some disadvantages such as high initial cost, high energy consumption and environmental impact during construction, and susceptibility to cracking due to thermal and moisture stresses. One of the ways to overcome these disadvantages is to use recycled coarse aggregate (RCA) as a partial or full replacement of natural coarse aggregate (NCA) in PCC. RCA is the aggregate obtained by crushing the waste concrete from construction and demolition sites. It can reduce the demand for virgin aggregate and the associated environmental impacts such as mining, transportation and disposal. It can also save costs and energy by reusing the existing materials.

However, using RCA in PCC also poses some challenges such as lower quality and strength, higher water absorption and porosity, presence of contaminants and alkali-silica reaction potential. Therefore, RCA needs to be properly processed, treated and tested before being used in PCC. Some of the methods to improve the quality of RCA are mechanical treatments, chemical treatments and biological treatments. Moreover, the mix design and performance of PCC with RCA need to be carefully evaluated and optimized according to the relevant standards and specifications.

The aim of this study is to design a rigid pavement by using RCA in PCC and to evaluate its properties and performance. The objectives are:

- To review the literature on the use of RCA in PCC and rigid pavement.
- To conduct laboratory tests on RCA and PCC with different replacement levels of RCA.
- To design a rigid pavement by using PCC with RCA according to the Indian standards and specifications.
- To analyze the structural behavior and durability of the designed rigid pavement by using finite element method (FEM).
- To compare the economic and environmental benefits of using RCA in rigid pavement with those of using NCA.

The scope of this study is limited to:

- The use of RCA from crushed concrete waste only.
- The replacement levels of RCA ranging from 0% to 100% by weight of NCA.
- The design of rigid pavement for low volume roads with a design life of 20 years.
- The use of Indian standards and specifications for PCC and rigid pavement design.

The expected outcomes of this study are:

- A comprehensive literature review on the use of RCA in PCC and rigid pavement.
- A database of laboratory test results on RCA and PCC with different replacement levels of RCA.
- A design procedure for rigid pavement by using PCC with RCA according to the Indian standards and specifications.
- A cost-benefit analysis and a life cycle assessment for comparing the economic and environmental benefits of using RCA in rigid pavement with those of using NCA.

1.1 Utilization of Recycled Coarse Aggregate

Utilization of Recycled Coarse Aggregate (RCA) is a topic of interest for environmental and economic reasons. RCA is the aggregate obtained by crushing the waste concrete from construction and demolition sites. It can be used as a partial or full replacement of natural coarse aggregate (NCA) in concrete, depending on the quality and properties of RCA. Some of the benefits of using RCA are:

- It reduces the demand for virgin aggregate and the associated environmental impacts such as mining, transportation and disposal.
- It saves costs and energy by reusing the existing materials.
- It enhances the durability and performance of concrete by improving the interfacial transition zone (ITZ) between the aggregate and the cement paste.

However, there are also some challenges and limitations of using RCA, such as:

- It has higher water absorption, lower density and lower strength than NCA due to the presence of adhered mortar and micro-cracks on the surface of RCA.
- It may contain contaminants such as gypsum, wood, metal, plastic and other materials that can affect the quality and consistency of concrete.
- It may cause alkali-silica reaction (ASR) due to the reactive silica in the recycled aggregate or the old cement paste.

Therefore, RCA needs to be properly processed, treated and tested before being used in concrete.

Some of the methods to improve the quality of RCA are:

- Mechanical treatments such as crushing, sieving, washing, heating and rubbing to remove the adhered mortar and reduce the porosity of RCA.
- Chemical treatments such as acid etching, carbonation and silane coating to improve the surface characteristics and bond strength of RCA.
- Biological treatments such as microbial induced carbonate precipitation (MICP) to fill the micro-cracks and pores of RCA with calcium carbonate crystals.

Using RCA in concrete is a promising way to achieve sustainability and circular economy in the construction industry. However, more research and development are needed to optimize the properties and performance of RCA and recycled aggregate concrete (RAC).

1.2 Limitations of Utilization of Recycled Coarse Aggregate

Utilization of recycled coarse aggregate (RCA) in concrete and pavement construction has many advantages such as reducing the environmental impact, saving costs and energy, and enhancing the durability and performance of the structures. However, there are also some limitations and challenges that need to be addressed before RCA can be widely used in practice. Some of the limitations are:

Downgrading of quality of concrete: RCA has lower quality and strength than natural coarse aggregate (NCA) due to the presence of adhered mortar and micro-cracks on the surface of RCA. This affects the workability, density, compressive strength, flexural strength, splitting tensile strength and elastic modulus of concrete.

Increase in water absorption capacity: RCA has higher water absorption capacity than NCA ranging from 3% to 9% due to its higher porosity. This requires more water and cement to achieve the desired workability and strength of concrete. It also increases the risk of shrinkage, cracking and freeze-thaw damage.

Presence of contaminants: RCA may contain contaminants such as gypsum, wood, metal, plastic and other materials that can affect the quality and consistency of concrete. These contaminants may interfere with the hydration process, reduce the bond strength between RCA and cement paste, or cause corrosion of reinforcement.

Lack of specifications and guidelines: There is a lack of uniform specifications and guidelines for using RCA in concrete and pavement construction. Different countries have different standards and regulations for RCA quality, testing methods, mix design, performance criteria and applications. This creates confusion and uncertainty among engineers, contractors and researchers.

Less durability of RCA: RCA may have less durability than NCA due to its lower resistance to abrasion, impact, fatigue and weathering. This may affect the service life and maintenance cost of concrete and pavement structures[12]. However, some studies have shown that RCA can improve the durability of concrete by mixing it with special materials like fly ash or by using biological treatments.

1.3 Rigid Pavement

Rigid pavement is a type of pavement that has a high flexural strength and can distribute the traffic load over a large area. It is usually made of Portland cement concrete (PCC) and reinforced with steel bars or fibers. Rigid pavement has many advantages such as long service life, low maintenance cost, good skid resistance and high load carrying capacity.

Rigid pavement is constructed by laying PCC slabs on a prepared subbase of granular material or directly on a granular subgrade. The slabs are divided into different sections by joints to allow for expansion and contraction due to temperature changes. The load is transmitted through the slabs to the underlying subgrade by flexure of the slabs.

Rigid pavement can be classified into two types based on the reinforcement used: jointed plain concrete pavement (JPCP) and jointed reinforced concrete pavement (JRCP). JPCP has no reinforcement or only a small amount of reinforcement to control cracking. JRCP has steel bars or wires embedded in the concrete to hold the cracks tightly together and increase the load transfer across the joints.

Rigid pavement design involves determining the thickness and reinforcement of the PCC slabs, the spacing and type of joints, and the quality and properties of the materials. The design criteria include the traffic load, the subgrade strength, the environmental conditions, and the performance requirements. Various methods and models are available for rigid pavement design, such as Westergaard's stress equation, American Association of State Highway and Transportation Officials (AASHTO) method, Indian Road Congress (IRC) method, etc.

The pavement having high flexural strength and constructed utilizing RCC or PCC is called rigid pavement.

It is simply a concrete road (either RCC or PCC).

- Rigid Pavement is divided into different slabs during construction, and a small gap is provided between the slabs so that concrete doesn't crack during expansion on summer days.
- This pavement transfers the wheel load to subgrade by slab action.
- Some examples of this pavement are PCC pavement, RCC pavement, and Prestressed concrete pavement.

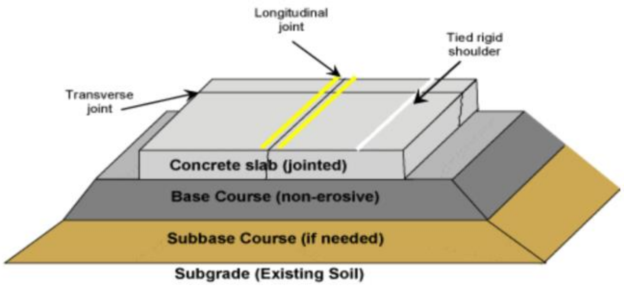

Figure 1.1- Rigid Pavement

Features of Rigid Pavement

Some features of rigid pavement are:

a. It transfers the wheel load to subgrade by slab action.

b. It requires joints.

c. Its initial construction cost is high.

d. Its durability is high.

e. It distributes wheel load uniformly.

f. It requires curing.

g. It doesn't require rolling (Compacting) of the surface.

h. It has high flexural strength.

Requirements of Good Rigid Pavement

- It should have a long-life design with low maintenance cost.
- It should be waterproof enough to protect sub-grade soil.
- It should have a high coefficient of friction to resist skidding.
- It should be smooth enough to provide comfort to the users.
- It should be structurally strong to withstand all types of loads.

Facts of Rigid Pavement

- They are also called single layer pavement.
- They may last up to 40 years if timely maintained and cared for.
- They may require asphalt for toping to reduce the noise during vehicle operation.
- The vehicle operation cost of rigid pavement is low.
- They are cheaper while considering the life-cycling cost.
- Maintenance cost is very low.

Advantages of Rigid Pavement

- Low maintenance and operation cost.
- Higher life span.
- It has high flexural strength.
- It has good resistance to petroleum products, oils, and chemicals.
- More environment-friendly than flexible pavement.
- It distributes loads in the broader area and can bear a large load due to slab action.

Disadvantages of Rigid Pavement

- High initial cost required for construction.
- Maintenance of rigid pavement is more complex than flexible pavement.
- Requires at least 28 days of curing before high traffic movement because concrete gains its 99% efficiency/strength in 28 days.
- Any excessive deformations occurring due to heavier wheel loads are not recoverable in this pavement type (settlement is permanent).

1.3.1 Rigid Pavement Design using Recycled Aggregate

Recycled aggregate (RA) is the aggregate obtained by crushing the waste concrete from construction and demolition sites. It can be used as a partial or full replacement of natural coarse aggregate (NCA) in concrete and pavement construction. Using RA in rigid pavement design has many benefits such as reducing the environmental impact, saving costs and energy, and enhancing the durability and performance of the structures.

However, using RA in rigid pavement design also poses some challenges such as lower quality and strength, higher water absorption and porosity, presence of contaminants and alkali-silica reaction potential of RA. Therefore, RA needs to be properly processed, treated and tested before being used in rigid pavement design. Some of the methods to improve the quality of RA are mechanical treatments, chemical treatments and biological treatments. Moreover, the mix design and performance of rigid pavement with RA need to be carefully evaluated and optimized according to the relevant standards and specifications.

Rigid pavement design using RA involves determining the thickness and reinforcement of the PCC slabs, the spacing and type of joints, and the quality and properties of the materials.

The design criteria include the traffic load, the subgrade strength, the environmental conditions, and the performance requirements. Various methods and models are available for rigid pavement design using RA, such as Westergaard's stress equation, American Association of State Highway and Transportation Officials (AASHTO) method, Indian Road Congress (IRC) method, etc.

Rigid pavement design using RA can be classified into two types based on the replacement level of RA: partial replacement and full replacement. Partial replacement means that only a certain percentage of NCA is replaced by RA in PCC slabs. Full replacement means that all NCA is replaced by RA in PCC slabs. The replacement level of RA depends on the availability, quality and cost of RA as well as the design requirements.

2. Literature Review

2.1 General

A various literature review on Experimental Study of Design of Rigid Pavement by using Recycled Coarse Aggregate with M30 Mix Design. Some of them are as follows:

Sahi, Pardeep, Sharma, V. (2023)

Concrete is one of the most widely used construction materials in the world, mainly due to its favorable features such as durability, versatility, satisfactory compressive strength, cost effectiveness. But with the depleting natural resources and the huge amount of concrete waste produced, it becomes essential to identify an effective way to solve the need of the moment. In this rapid industrialized world, recycling construction material plays an important role to preserve the natural resources. In this research, Recycled Coarse Aggregates (RCA) from demolished slab pieces was used. These demolished slab pieces are crushed to suitable size and reused as recycled coarse aggregate. Natural sand used as fine aggregate. Concrete industry, uses 12.6 billion tons of raw materials each year, is the largest user of natural resources in the world. The environmental impact of production of raw ingredients of concrete (such as cement and coarse and fine aggregates) is considerable. In this paper The mix design has been done by trial and error method. The mix proportions are calculated as per IS code. The design procedure as per IS code and IRC: 44-2008 is used in mix design of M30 grade cement concrete. The w/c ratio is taken 0.5% for all the mixes. Hence, Coarse aggregates was replaced in percentages of 0%, 20%, 40 %, 60 %, 80 %, 100 % with recycled coarse aggregates 150 × 150× 150mm, Beam and Cylinder moulds were used for casting.

Mohamad, S. A., Al-Haydari, I. S., Masood, G. G., & Khudhur, H. M. N. (2022)

Polyester concrete PC is composed of aggregate, polyester resin as binding material, and fillers when needed. Sustainable polyester concrete pavement SPCP is composed of recycled aggregate, polyester resin as binding material, and fine waste material used as fillers like fly ash. SPCP can be used as rigid pavement construction. Because of its properties like high compressive strength, high flexural strength, fast curing, high specific strength, and resistance to chemical attacks. A high flexural strength is the main requirement for pavement structures to resist cyclic load from traffic. The present study attempted to investigate the physical and mechanical properties of sustainable polyester concrete pavement SPCP contain different types of recycled aggregates RA in addition to natural aggregate, and fly ash as a mineral filler. The study used reclaimed asphalt pavement RAP, recycled concrete aggregate RCA, and crushed bricks aggregate CBA, with different percentages by weight (0%, 25%, 75%, and 100%) as a replacement with natural aggregate NA. The test results indicated that aggregate characteristics have a significant influence on the properties of SPCP. The best performance, especially in flexural strength, was obtained with recycled concrete aggregate.

Makul, N., Fediuk, R., Amran, M., Zeyad, A. M., Klyuev, S., Chulkova, I., Azevedo, A. (2021)

Currently, a number of disadvantages hampers the use of recycled concrete aggregates (RCA). The current review proves that concretes made with complete replacement of natural aggregate with RCA allow the production of high-quality concrete. One of the possibilities for improving concrete properties with RCA is the use of extended curing and pozzolanic materials with varying cement ratios. The potential use of RCA concretes is in the production of high-value materials that increase environmental and financial benefits. RCA have strong potential in the development of a new generation of concrete and stimulate economic activity in many countries in addition to optimizing natural resources. Economic benefits include minimal travel costs; cheaper sources of concrete than newly mined aggregates; reduction of the landfill area required for the placement of concrete waste; the use of RCA minimizes the need for gravel extraction, etc. The proposed strategy could be to sequentially separate demolition waste such as roof finishes, waterproof materials, interior and exterior materials, etc. Closing life cycles is the main approach used for efficient structures for the recycling and reuse of construction and demolition waste in the production and recovery of materials, especially when recycling and reusing materials. In the life cycle, the recycling of recovered materials allows them to be used for new construction purposes, avoiding the use of natural concrete aggregates. Government, design institutes, construction departments and project managers should be involved in the creation and use of RCA. In demolition and construction, the main players are the project owners. Their obligations, expectations and responsibilities must be properly aligned. For the past 20 years, recycled concrete aggregate from demolition and construction waste has been considered as an alternative to pure concrete in structural concrete to minimize the environmental impact of construction waste and demolition waste and the conversion of natural aggregate resources. It is now recognized that the use of RCA for the generations of concrete is a promising and very attractive technology for reducing the environmental impact of the construction sector and conserving natural resources. In the market, the selling price is not an obstacle for market applications of RCA, as there are scenarios in which their cost is lower than the cost of products made from conventional building materials. This is more of an acceptance factor in the market for recycled concrete aggregates. In this sector, the lack of identification, accreditation and uniform quality certification systems and their narrow application cause some marketing problems. With proper RCA preparation, concrete with standard physical and mechanical properties and performance characteristics can be obtained.

Manjunatha, Rakesh V. D, Dr. V. G. Mutalik Desai (2020)

In developing countries like India, the deposition of construction and demolition waste material is in the rate of millions of tons in a year, these deposited waste material contains a reusable materials like coarse aggregates and fine aggregates with a content of cement mortar adhered to it, sustainable development becomes when they are effectively used for production of concrete by preserving the natural resources, on the other hand If they are not properly employed that will become source of pollution and occupy landfill space. The present study investigating that the possibility of replacing the natural coarse aggregates (NCA) with recycled coarse aggregates (RCA) in a conventional concrete used in pavement quality concrete surface, in this study mix design is prepared for M40 grade is being used with a different proportions as NCA with RCA i.e 0:100, 30:70, 70:30, and 100:0. Total are considered in a percentage to the weight of natural coarse aggregates and the physical properties of natural and recycled aggregates has found by conducting the basic tests on aggregates and before to cast a specimens, we have tested a three cubes for M40 grade to fix a final mix proportion. And the optimum percentage of replacement of NCA with RCA was determined by conducting the tests for various proportion mixes of RCA and NCA and the required 28 days characteristic strength for pavement quality concrete is being evaluated in this project, The ultimate aim is to attain a suitable strength on usage of recycled coarse aggregates for pavement quality concrete thus to implement cost effective nature and durability.

Murthi, P., Almas, K., Poongodi, K., & Gobinath, R. (2020)

The investigation is intended to evaluate the impact of substitution of demolished concrete debris as coarse aggregate (CA) in pavement quality concrete (PQC). The strength characteristics of PQC such as compressive strength, tensile strength, flexural strength and impact strength after adding recycled coarse aggregate (RCA) are experimentally determined in laboratory environment. Specimens of M30 grade concrete were prepared and tested. The RCA was substituted up to 50% by replacing CA content. Based on the investigation results, it was found that reduction of slump value due to the substitution of RCA in concrete. There is no remarkable reduction of compressive strength and flexural strength up to 30% and 40 % replacement of CA respectively in all the curing periods. The impact strength was reduced due to addition of RCA and observed 8% reduction after adding 20% RCA. It is suggested that RCA may be used up to 20% as CA in PQC.

Navaz, P., Paul, A. (2020)

Pervious concrete is a very special type of concrete with high porosity made using large aggregates with little to no fine aggregates. It allows water from precipitation and other sources to pass directly through thereby reducing the runoff from the site and allowing ground water recharge. The study proposes the replacement of natural coarse aggregates in the mixture, with recycled coarse aggregates. The utilization of recycled coarse aggregates from construction and demolition wastes serves as a sustainable solution, which reduces the overall cost and environmental pollution. In this paper, a review on mechanical properties and permeability indices of pervious concrete made with recycled coarse aggregates is studied.

Silva, R. V., De Brito, J., & Dhir, R. K. (2019)

In the light of the ever-increasing need of circular economy in the construction industry and of the recent advances in research and development on the use of recycled aggregates, produced from construction and demolition waste, in new construction materials, this paper presents a compilation of representative case studies of several applications, namely recycled aggregates in unbound, hydraulically-bound and bitumen-bound applications, as well as in (non-)structural concrete in road and building construction. Experience has shown that, in spite of the positive outcomes and comprehensive know-how gained over the course of several years in those exploratory studies, there is a considerable underuse of recycled aggregates mostly due to lack of confidence in the material amongst contractors and designers. This paper, using a range of case studies undertaken in several countries worldwide, highlights the technical viability and appropriateness of using recycled aggregates in a broad range of construction applications.

Poongodi, K., Murthi, P., Gobinath, R., Srinivas, A., & Sangeetha, G. (2019)

The mechanical properties of pavement quality concrete using recycled concrete aggregate (RCA) obtained from the concrete debris as coarse aggregate (CA) are experimentally determined and presented in this paper. M40 grade concrete was tested with conventional granite CA before adding RCA and then CA was replaced by RCA at the rate of 10, 20, 30, 40 and 50%. The concrete was tested in fresh state by slump and compaction factor (CF) value to evaluate variations in workability. The compressive strength and flexural strength of concrete were conducted to ascertain performance in hardened state. The water absorption test was conducted as a part of durability test. The gradual reduction of slump value was noticed after adding RCA as aggregate in concrete. The slump value had been maintained by substituting the superplastizer without varying the w/c ratio. The strength properties were calculated after 3, 7 and 28 days curing. No significant reduction of strength was observed up to the 30% replacement of RCA and the strength was reduced by adding more than 30% of RCA. From the results obtained in this investigation, it was concluded that the RCA could be used up to 40% as CA for pavement quality concrete.

Bilal, M. K., Mohit (2019)

Concrete is one of the most widely used construction materials in the world, mainly due to its favorable features such as durability, versatility, satisfactory compressive strength, cost effectiveness. But with the depleting natural resources and the huge amount of concrete waste produced, it becomes essential to identify an effective way to solve the need of the moment. In this rapid industrialized world, recycling construction material plays an important role to preserve the natural resources. In this research, Recycled Coarse Aggregates (RCA) from demolished slab pieces was used. These demolished slab pieces are crushed to suitable size and reused as recycled coarse aggregate. Natural sand used as fine aggregate. Concrete industry, uses 12.6 billion tons of raw materials each year, is the largest user of natural resources in the world. The environmental impact of production of raw ingredients of concrete (such as cement and coarse and fine aggregates) is considerable. In this paper The mix design has been done by trial and error method. The mix proportions are calculated as per IS code. The design procedure as per IS code and IRC: 44-2008 is used in mix design of M30 grade cement concrete. The w/c ratio is taken 0.5% for all the mixes. Hence, Coarse aggregates was replaced in percentages of 0%, 20%, 40 %, 60 %, 80 %, 100 % with recycled coarse aggregates 150 × 150 × 150mm, Beam and Cylinder moulds were used for casting.

Mamdyal, K. R., Jawalkar, G. C. (2018)

In this research study, Natural coarse aggregates are replaced by Recycled coarse aggregates (RCA) with various percentage of RCA i.e., 25%, 50%, 75%, 100%. An Experimental work was performed to determine the compressive strength of recycled coarse aggregate concrete and to compare them with those of concrete made using natural coarse aggregate. Comparison of Different Grades i.e., M25, M30, M35.

Verian, K. P., Ashraf, W., & Cao, Y. (2018)
This manuscript presents a review of the potential and challenge of using recycled concrete aggregate (RCA) as the substitute for natural aggregate (NA) in concrete mixtures. Using RCA in concrete preserves the environment by reducing the need for opening new aggregate quarries and decreases the amount of construction waste that goes into landfill. The properties of RCA such as specific gravity, absorption, and the amount of contaminant present in it contribute to the strength and durability of concrete. The quality of RCA depends on the features of the original aggregate and the condition of the demolished concrete. Some researchers have reported that the use of RCA degrades concrete properties while others have successfully produced RCA concrete with a performance that matched normal concrete (NC). In addition to the influence of RCA to concrete properties, this paper also evaluates multiple techniques to improve the performance of RCA concrete, reported cost savings in concrete production and recommendations regarding the application of RCA in concrete.

Kumar, J., Dalal, D. (2018)
In this paper a review aims to find the possibility of the structural usage of recycled coarse aggregate in lieu or mixed with natural aggregates, based on better understanding of behaviour of recycled aggregate in concrete structures experimenting fresh and hardened concrete, mixtures containing recycled aggregates. The literature review provides an overview of sustainability and key performance indicators, the material properties of recycled aggregate concrete both as an aggregate and in concrete, concrete mixture and proportioning designs with recycled aggregate concrete, performance of existing recycled aggregate concrete pavements, and the implementation of recycled aggregate concrete highlighting some examples where recycled aggregate concrete has been used successfully. Use of recycled aggregate in pavement concrete can be useful for environmental protection and economical terms. Recycled aggregates are the materials for the future. It is well known fact that it is giving little lower strength than natural aggregate concrete. Though, if it is used up to 20% of replacement, than it can give almost similar strength to that of natural aggregate concrete. Hence it was necessary to improve strength of recycled aggregate concrete for higher recycled aggregate content. Silica fume is very popular material used for strength improvement. Hence popular mix of M20 was checked with different % of silica fume combination. 5%, 10% and 15% of silica fume were replaced with cement and 20%, 30% and 40% of recycled aggregates were replaced with natural aggregate and results were analyzed.

Jagadeesh, S., Rao, J. V., Vasavadatta, CH. (2018)
In countries like India every year millions of tons of construction and demolition waste are produced which contains reusable materials like coarse and fine aggregates mixed with cement mortar. If they are not properly employed, they will become source of pollution and occupy land fill space. On the other hand, if they are effectively used for producing concrete it leads to sustainable construction approach. The present experimental investigation examines the possibility of replacing natural coarse aggregate (NCA) with recycled coarse aggregate (RCA) in conventional concrete used in rigid pavements. The various combinations of RCA and NCA (0:100, 10:90, 20:80, 30:70) % are considered in M40 concrete mix. The optimum percentage of replacement of NCA with RCA was determined. In the later stage the combination of both RCA and Recycled fine aggregate (RFA) in various proportions (0:100, 25:75, 50:50, 75:25) is investigated and found the optimum one based on the economic feasibility.

Kalyani, R., Rao, P. N., Bharathi, M. D. V. M. (2018)
Concrete made with Portland cement has certain characteristics: it is relatively strong in compression but weak in tension and tends to be brittle. These two weaknesses have limited its use. Another fundamental weakness of concrete is that cracks start to form as soon as concrete is placed and before it has properly hardened. These cracks are major cause of weakness in concrete particularly in large on-site applications leading to subsequent fracture and failure and general lack of durability. The weakness in tension can be overcome by the use of conventional rod reinforcement and to some extent by the inclusion of a sufficient volume of certain fibers. Fiber reinforced concrete (FRC) may be defined as a composite material made with Portland cement, aggregate, and incorporating discrete discontinuous fibers. Fiber- reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibres that are uniformly distributed and randomly oriented – each of which lend varying properties to the concrete. In addition, the character of fibre-reinforced concrete changes with varying concretes, fibre materials, geometries, distribution, orientation, and densities. In this experimental investigation, an attempt has made to find out strength related tests like Compressive Strength, Split Tensile Strength, Flexural Strength using Pure concrete, steel fibers and Glass Fibers with to volume fraction of 0.0%,0.25%,0.5%, 0.75% and 1% and for aspect ratio and considered for M40 Grade of concrete. The results of the tests showed that the strength properties are enhanced due to addition of glass fibers.

Rodríguez, C., Miñano, I., Aguilar, M. Á., Ortega, J. M., Parra, C., & Sánchez, I. (2017)
In recent years there has been an increasing tendency to recycle the wastes generated by building companies in the construction industry, demolition wastes being the most important in terms of volume. The aim of this work is to study the possibility of using recycled aggregates from construction and demolition wastes in the preparation of precast non-structural concretes. To that purpose, two different percentages (15% and 30%) of natural aggregates were substituted by recycled aggregates in the manufacture of paving blocks and hollow tiles. Dosages used by the company have not been changed by the introduction of recycled aggregate. Precast elements have been tested by means of compressive and flexural strength, water absorption, density, abrasion, and slipping resistance. The results obtained show the possibility of using these wastes at an industrial scale, satisfying the requirements of the Spanish standards for these elements.

Gupta, R., Puppala, H., & Rajesh, N. (2015)
Huge quantities of construction wastes, demolition, and electronic wastes are being generated these days in many of the countries and the disposal of them has become a serious problem. This study is an integrated experiment in which different combinations of e-wastes and recycled coarse aggregate together are used as a substitute of conventional aggregate. Recycled aggregates from site-tested concrete specimens were collected and are integrated with the e-waste by altering the proportions of these wastes. The compressive strength of M20 mix designed is assessed by casting cubes and the flexural strength by prisms. This study is carried out to

ensure the usage of integrated- waste and the recycled coarse aggregate as a replacement of coarse aggregate. Experimental study is carried out to find if the e-waste strips can be used as the reinforcement instead of steel. Results are checked against the standards of IRC to use for the sub-grade of the pavement.

Ahmed, M. S., & Vidyadhara, H. S. (2013)

Concrete is one of the most widely used construction material in the world. Increase in population growth is leading to increase in various demands like cultivation, transportation, construction etc. Nowadays, there is a tremendous increase in the demand for construction works like residential buildings, bridges, dams, roads etc. and because of this increase in demand the availability of sources for concrete ingredients is getting difficult. Hence people are looking for alternative sources for the concrete ingredients in order to full fill their requirements. This dissertation work deals with the study of strength of concrete incorporating Recycled Aggregate concrete (R.A.C). The main objective of this investigation is to find out up to what percentage the Natural Coarse Aggregate (N.C.A.) can be replaced by recycled coarse aggregate (R.C.A) in the concrete mix and to find out the extra quantity of cement to be added for each percentage replacement by R.C.A. to achieve its target mean strength. In this ongoing project work it is concentrated only on the use of R.C.A. A series of tests were carried out to determine the compressive strength, split tensile strength, flexural strength with and without recycled aggregates. Natural coarse aggregates in concrete were replaced with 0%, 20%, 40%, 60%, 80% and 100% of crushed concrete coarse aggregates. For the strength characteristics, the result showed a gradual decrease in compressive strength, split tensile strength, flexural strength and modulus of elasticity as the percentage of recycled aggregate is increased.

Angulo, S. C., Carrijo, P. M., Figueiredo, A. D. D., Chaves, A. P., & John, V. M. (2010)

The properties of recycled aggregate produced from mixed (masonry and concrete) construction and demolition (C&D) waste are highly variable, and this restricts the use of such aggregate in structural concrete production. The development of classification techniques capable of reducing this variability is instrumental for quality control purposes and the production of high-quality C&D aggregate. This paper investigates how the classification of C&D mixed coarse aggregate according to porosity influences the mechanical performance of concrete. Concretes using a variety of C&D aggregate porosity classes and different water/cement ratios were produced and the mechanical properties measured. For concretes produced with constant volume fractions of water, cement, natural sand and coarse aggregate from recycled mixed C&D waste, the compressive strength and young modulus are direct exponential functions of the aggregate porosity. Sink and float technique is a simple laboratory density separation tool that facilitates the separation of cement particles with lower porosity, a difficult task when done only by visual sorting. For this experiment, separation using a 2.2 kg/dm³ suspension produced recycled aggregate (porosity less than 17%) which yielded good performance in concrete production. Industrial gravity separators may lead to the production of high-quality recycled aggregate from mixed C&D waste for structural concrete applications.

Tabsh, S. W., & Abdelfatah, A. S. (2009)

Many structures in the middle-east's Gulf region are now either reaching the end of their design life or were not constructed according to the specifications. Demolition or maintenance work on such structures results in large amount of concrete rubbles. Recycling concrete wastes will lead to reduction in valuable landfill space and savings in natural resources. The objective of this study is to investigate the strength of concrete made with recycled concrete coarse aggregate. The variables that are considered in the study include the source of the recycled concrete and target concrete strength. The toughness and soundness test results on the recycled coarse aggregate showed higher percentage loss than natural aggregate but remained within the acceptable limits. The compressive and splitting tensile strengths of concrete made with recycled coarse aggregate depend on the mix proportions. In general, the strength of recycled concrete can be 10–25% lower than that of conventional concrete made with natural coarse aggregate.

Rao, A., Jha, K. N., & Misra, S. (2007)

Construction and Demolition (C&D) waste constitutes a major portion of total solid waste production in the world, and most of it is used in landfills. Research by concrete engineers has clearly suggested the possibility of appropriately treating and reusing such waste as aggregate in new concrete, especially in lower-level applications. This paper discusses different aspects of the problem beginning with a brief review of the international scenario in terms of C&D waste generated, recycled aggregates (RA) produced from C&D waste and their utilization in concrete and governmental initiatives towards recycling of C&D waste. Along with a brief overview of the engineering properties of recycled aggregates, the paper also gives a summary of the effect of use of recycled aggregate on the properties of fresh and hardened concrete. The paper concludes by identifying some of the major barriers in more widespread use of RA in recycled aggregate concrete (RAC), including lack of awareness, lack of government support, non-existence of specifications/codes for reusing these aggregates in new concrete.

2.2 Research Gap

Following gaps are identified from the structured review of literature:

- The literature seems to be the use of recycled coarse aggregate as alternative natural coarse aggregate is very less study.
- The literature seems to be Compressive and Flexural Strength of Concrete of recycled coarse aggregate is very less study.
- Little literature is available related to Recycled Coarse Aggregate for different Grade of Mix Design.

2.3 Problem Statement

From the research gap, it is found that recycled mixture was unbelievably effective for rising the strength characteristics, cracking, and workability of the concrete. once we have a tendency to use the resource, we have a tendency to discover that there were low characteristics of strength, workability, and cracking so to spice up that strength we have got a bent to use recycled mixture thus we have got a bent to found improvement among the strength and workability of the concrete at varied proportions there was a change among the strength of the concrete and it provides higher result as compared to the normal concrete.

- Concrete production requires natural coarse aggregate, which is limited and expensive.
- Waste concrete disposal causes environmental and economic issues.

- Recycled coarse aggregate (RCA) is an alternative material obtained from crushing demolished concrete.
- RCA can save natural resources, landfill space and pavement cost.
- Use of high-quality recycled coarse aggregate.
- Use of a design method that accounts for the properties of RCA.
- Use of quality control measures to ensure that the RCA used in a rigid pavement meets the required specifications. These quality control measures can include visual inspection, testing, and certification.
- Use of proper construction practices when constructing a rigid pavement using RCA. These construction practices should include proper compaction and curing.
- Use of proper construction practices when constructing a rigid pavement using RCA. These construction practices should include proper compaction and curing.

For M30 Mix Design:

- The M30 mix design is a type of concrete mix that is designed to have a compressive strength of at least 30 MPa.
- The M30 mix design is typically used for rigid pavements that are subject to heavy traffic loads.
- The M30 mix design can be made using RCA, but it is important to use high-quality RCA that has been properly processed.
- The M30 mix design should be developed using trial mixes and should be tested to ensure that it meets the required strength and durability criteria.
- The M30 mix design should be constructed using proper compaction and curing practices.

Therefore, some of the research questions that can be formulated for this problem statement are:

- How to remove or reduce the adhered mortar on RCA and improve its quality and consistency?
- How to optimize the mix design and proportioning of RCA in concrete pavement with M30 mix design to achieve the desired strength, durability, and workability?
- How to prevent or mitigate ASR in RCA concrete pavement with M30 mix design and enhance its long-term performance?
- How to evaluate the environmental, economic, and social benefits of using RCA in concrete pavement with M30 mix design compared to natural aggregates?
- How to test the properties and performance of RCA concrete pavement with M30 mix design using laboratory and field methods?

2.4 Objectives of The Research Work

The main object of the present work was to find the strength value of concrete by replacing it using recycled aggregate.

- To find out the various strength of cube and beam for concrete using recycled aggregate.
- Study the properties of recycled coarse aggregate and its suitability for use in rigid pavements.
- Develop a mix design for M30 grade concrete using recycled coarse aggregate.
- Evaluate the performance of concrete pavements made with recycled coarse aggregate in terms of 7, 14 and 28 Days compressive strength, flexural strength, and durability.
- To evaluate the environmental benefits of using RCA as a replacement for NA.
- To investigate the feasibility and cost-effectiveness of using RCA in rigid pavement construction.
- To propose a mix design for M30 grade concrete using RCA as coarse aggregate for rigid pavement construction.

3. CONCLUSIONS

Let us conclude based on the key findings:

- The study found what optimum percentage of RCA can be effectively used as a partial replacement for natural coarse aggregate (NCA) in rigid pavement design.
- By incorporating RCA, concrete production becomes more environmentally friendly. Additionally, using RCA can lead to cost savings, which is beneficial for construction projects.
- The study supports whether using recycled coarse aggregate in rigid pavement design can be a sustainable option. This aligns with the growing emphasis on environmentally conscious practices in the construction industry.
- Whether RCA replacement up to 50% or more is safe, what additional precautions may be required when exceeding this limit.
- Ensuring adequate strength and durability becomes important when using higher percentages of RCA.
- Whether the study suggests expanding research to other concrete mixes, such as high-performance and self-consolidating concrete.
- Whether long-term durability testing, including freeze-thaw, can provide valuable insights.

REFERENCES

1. Ahmed, M. S., & Vidyadhara, H. S. (2013). Experimental study on strength behaviour of recycled aggregate concrete. International Journal of Engineering Research & Technology, 2(10), 76-82.
2. Al Adday, F., Awad, A., Al-Kharabsheh, M. R. S., & Zeno, A. (2018). Early-High-Strength concrete pavement with recycled aggregates and silica. International Journal of Civil Engineering and Technology, 9 (2), 990-1004.
3. Angulo, S. C., Carrijo, P. M., Figueiredo, A. D. D., Chaves, A. P., & John, V. M. (2010). On the classification of mixed construction and demolition waste aggregate by porosity and its impact on the mechanical performance of concrete. Materials and Structures, 43, 519-528.
4. Bakash, S. A., Sowmith, Rakesh, C. G., Rahul, B.G. (2013) A Review of The Use of Recycled Materials in Rigid Pavements. International Journal of Engineering Research & Technology.2(4), 1308-1313.
5. Bilal, M. K., Mohit (2019). An Experimental Study on the use of Recycled Aggregates in Rigid Pavement. Journal of Emerging Technologies and Innovative Research, 6(6), 540-548.
6. Cavalline, T., Snyder, M. B., & Taylor, P. (2022). Use of Recycled Concrete Aggregate in Concrete Paving Mixtures (No. FHWA-HIF-22-020).
7. Chan, R., Santana, M. A., Oda, A. M., Paniguel, R. C., Vieira, L. B., Figueiredo, A. D., & Galobardes, I. (2019). Analysis of potential use of fibre reinforced recycled aggregate concrete for sustainable pavements. Journal of cleaner production, 218, 183-191.
8. Deepak, O. P., Krishnakumar, R., Krishnagopal, M., & Vishnu, P. Reuse of Coarse Aggregate as Recycled Aggregate in Concrete. Materials Research Proceedings, 23.
9. Etxeberria, M., Vázquez, E., Marí, A., & Barra, M. (2007). Influence of amount of recycled coarse aggregates and

production process on properties of recycled aggregate concrete. Cement and concrete research, 37(5), 735-742.
10. Gao, D., & Zhang, L. (2018). Flexural performance and evaluation method of steel fiber reinforced recycled coarse aggregate concrete. Construction and Building Materials, 159, 126-136.
11. Gupta, R., Puppala, H., & Rajesh, N. (2015). Application of recycled coarse aggregates and E-waste for pavements with low traffic. IOSR Journal of Mechanical and Civil Engineering, 12(2), 64-70.
12. Jagadeesh, S., Rao, J. V., Vasavadatta, CH. (2018) An Experimental Study on the Effective use of Recycled Concrete Aggregates in Rigid Pavements. International Journal of Civil Engineering and Technology., 9(8), pp. 1519, IAEME Publication.
13. Jindal, A., Ransinchung, G. D., & Kumar, P. (2014, October). Recycled Concrete Aggregates for Rigid Pavements: A Review. In International Conference on Sustainable Civil Infrastructure (ICSCI 2014), IIT Hyderabad.
14. Kalyani, R., Rao, P. N., Bharathi, M. D. V. M. (2018) An Experimental Investigation on Strength Properties of Fiber Reinforced Concrete (Steel and Glass Fibers). International Journal of Engineering Sciences & Research Technology. 7(6), 507-526.
15. Kumar, J., Dalal, D. (2018). Innovation in Strength Properties of Rigid Pavement Concrete by Partial Mixing of Silica Fume and Recycled Coarse Aggregate: A Review. International Research Journal of Engineering and Technology., 05(03), 1741-1745.
16. Kumar, R., Singh. G. (2019). Evaluation of Recycled Concrete Aggregate and Rice Husk Ash with Polyvinyl Alcohol Fibre for Mechanical Properties of Concrete. International Journal of Civil Engineering and Technology, 10(03), pp. 1903–1910.
17. Makul, N., Fediuk, R., Amran, M., Zeyad, A. M., Klyuev, S., Chulkova, I., Azevedo, A. (2021). Design strategy for recycled aggregate concrete: A review of status and future perspectives. Crystals, 11(6), 695.
18. Mamdyal, K. R., Jawalkar, G. C. (2018). Sustainable Use of Recycled Aggregate in Concrete. International Journal of Innovations in Engineering Research and Technology, 5(8), 15-19. Novateur Publications.
19. Manchanda, M. (2017) Analysis of Rigid Pavement by Varying Thickness and Using RCA. International Journal of Science and Research. 7(6), 1579-1583.
20. Manjunatha, Rakesh V. D, Dr. V. G. Mutalik Desai (2020). Use of Recycled Coarse Aggregates in Pavement Quality Concrete for Sustainable Development. International Research Journal of Engineering and Technology, 07(06), (pp. 4486-4491).
21. Manjunatha, Rakesh V. D, Dr. V. G. Mutalik Desai (2020, June). Use of Recycled Coarse Aggregates in Pavement Quality Concrete for Sustainable Development. International Research Journal of Engineering and Technology (Vol. 7, No. 6, p. 4486)
22. Mohamad, S. A., Al-Haydari, I. S., Masood, G. G., & Khudhur, H. M. N. (2022). Properties of sustainable polyester concrete pavement with various types of recycled aggregates. Road Materials and Pavement Design, 23(5), 973-991.
23. Murthi, P., Almas, K., Poongodi, K., & Gobinath, R. (2020). Properties of pavement quality concrete prepared with recycled coarse aggregate. International Journal of Recent Technology and Engineering, 8(5), 3186-3192.
24. Muscalu, M. T., & Andrei, R. (2011). Use of recycled aggregates in rigid pavement construction. Buletinul Institutului Politehnic din lasi. Sectia Constructii, Arhitectura, 57(2), 69.
25. Muscalu, M. T., & Andrei, R. (2011). Use of recycled aggregates in rigid pavement construction. Buletinul Institutului Politehnic din lasi. Sectia Constructii, Arhitectura, 57(2), 69.
26. Navaz, P., Paul, A. (2020). A Review on Influence of Recycled Aggregates in Pervious Concrete. International Journal of Creative Research Thoughts, 8(10), 1035-1038.
27. Pallath, V. S., Gangha, G., Ramasamy, N.G. (2015) Experimental Study on Strength Characteristics of Concrete with Recycled Aggregates and Analysis of Its Effective uses in Road Works. International Journal of Research in Engineering and Technology. 04(03), 258-262.
28. Plaza, P., del Bosque, I. S., Frías, M., de Rojas, M. S., & Medina, C. (2021). Use of recycled coarse and fine aggregates in structural eco-concretes. Physical and mechanical properties and CO2 emissions. Construction and Building Materials, 285, 122926.
29. Plaza, P., del Bosque, I. S., Frías, M., de Rojas, M. S., & Medina, C. (2021). Use of recycled coarse and fine aggregates in structural eco-concretes. Physical and mechanical properties and CO2 emissions. Construction and Building Materials, 285, 122926.
30. Poongodi, K., Murthi, P., Gobinath, R., Srinivas, A., & Sangeetha, G. (2019). Mechanical properties of pavement quality concrete using recycled aggregate. Int J Innov Technol Explor Eng, 9, 33-38.
31. Pourkhorshidi, S., Sangiorgi, C., Torreggiani, D., & Tassinari, P. (2020). Using recycled aggregates from construction and demolition waste in unbound layers of pavements. Sustainability, 12(22), 9386.
32. Rana, A., Sharma, A., & Jassal, K. (2021, November). Design of Rigid Pavement by Self Cured Concrete Utilizing Coarse Fly Ash Aggregates and Curing Admixture. In IOP Conference Series: Earth and Environmental Science (Vol. 889, No. 1, p. 012011). IOP Publishing.
33. Rao, A., Jha, K. N., & Misra, S. (2007). Use of aggregates from recycled construction and demolition waste in concrete. Resources, conservation and Recycling, 50(1), 71-81.
34. Remišová, E., Decký, M., Mikolaš, M., Hájek, M., Kovalčík, L., & Mečár, M. (2016, October). Design of road pavement using recycled aggregate. In IOP Conference Series: Earth and Environmental Science (Vol. 44, No. 2, p. 022016). IOP Publishing.
35. Rodríguez, C., Miñano, I., Aguilar, M. Á., Ortega, J. M., Parra, C., & Sánchez, I. (2017). Properties of concrete paving blocks and hollow tiles with recycled aggregate from construction and demolition wastes. Materials, 10(12), 1374.
36. Rudnicki, T., & Jurczak, R. (2020). Recycling of a Concrete Pavement after over 80 Years in Service. Materials, 13(10), 2262.
37. Ryou, J. S., & Lee, Y. S. (2014). Characterization of recycled coarse aggregate (RCA) via a surface coating method. International Journal of Concrete Structures and Materials, 8(2), 165-172.
38. Safiuddin, M., Alengaram, U. J., Rahman, M. M., Salam, M. A., & Jumaat, M. Z. (2013). Use of recycled concrete aggregate in concrete: a review. Journal of Civil Engineering and Management, 19(6), 796-810.
39. Senaratne, S., Gerace, D., Mirza, O., Tam, V. W., & Kang, W. H. (2016). The costs and benefits of combining recycled aggregate with steel fibres as a sustainable, structural material. Journal of cleaner production, 112, 2318-2327.
40. Silva, R. V., De Brito, J., & Dhir, R. K. (2019). Use of recycled aggregates arising from construction and demolition waste in new construction applications. Journal of Cleaner Production, 236, 117629.
41. Sivamani, J., Renganathan, N. T., & Palaniraj, S. (2021). Enhancing the quality of recycled coarse aggregates by different treatment techniques—a review. Environmental Science and Pollution Research, 1-20.

42. Tabsh, S. W., & Abdelfatah, A. S. (2009). Influence of recycled concrete aggregates on strength properties of concrete. Construction and building materials, 23(2), 1163-1167.
43. Tam, V. W., Soomro, M., & Evangelista, A. C. J. (2018). A review of recycled aggregate in concrete applications (2000–2017). Construction and Building materials, 172, 272-292.
44. Tuladhar, R., Marshall, A., & Sivakugan, N. (2020). Use of recycled concrete aggregate for pavement construction. In Advances in Construction and Demolition Waste Recycling (pp. 181-197). Woodhead Publishing.
45. Verian, K. P., Ashraf, W., & Cao, Y. (2018). Properties of recycled concrete aggregate and their influence in new concrete production. Resources, Conservation and Recycling, 133, 30-49.
46. Verian, K. P., Whiting, N. M., Olek, J., Jain, J., & Snyder, M. B. (2013). Using recycled concrete as aggregate in concrete pavements to reduce materials cost (No. FHWA/IN/JTRP-2013/18). Purdue University. Joint Transportation Research Program.
47. Wang, B., Yan, L., Fu, Q., & Kasal, B. (2021). A comprehensive review on recycled aggregate and recycled aggregate concrete. Resources, Conservation and Recycling, 171, 105565.