IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

International Conference on Interdisciplinary Global Research in Adaptation, Transformation & Engineering

INTEGRATE 2025

Geetanjali Institute of Technical Studies (GITS)

Vol. 12, SPECIAL ISSUE 2, NOVEMBER 2025

DOI: 10.17148/IARJSET/INTEGRATE.2025.12241

Innovative Utilization of Waste And By-Product Material In Civil Infrastructure: A Comprehensive Review of Fly Ash, Rice Hush Ash' Recycled Rubber' And Plastic Application

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Abstract: The rapid growth in waste generation and the pressing need for sustainable development have driven extensive research into the valorization of industrial and agricultural by-products in civil engineering. This review critically examines advancements in utilizing fly ash, rice husk ash, recycled plastics, and rubber waste for concrete production, soil stabilization, and pavement construction. Studies reveal that fly ash and rice husk ash serve as promising supplementary cementitious materials, improving strength, durability, and shrinkage properties in concrete and enhancing subgrade characteristics in road construction. The incorporation of recycled plastic aggregates in cementitious composites offers environmental benefits but challenges remain regarding mechanical performance and long-term durability. Furthermore, crumb rubber from waste tires, when incorporated into bituminous mixes, significantly enhances the rutting, fatigue, and thermal resistance properties of pavements. The synergistic use of these waste materials promotes circular economy principles, mitigates environmental hazards, and leads to cost-effective and eco-friendly construction practices. This review identifies key mechanisms, performance trends, and practical limitations, and highlights areas for further research to overcome current challenges in the civil engineering world.

Keyword: Fly Ash; Rice Husk Ash (RHA); Recycled Plastic; Crumb Rubber; Sustainable Construction; Supplementary Cementitious Materials (SCM); Waste Utilization; Eco-Friendly Concrete; Pavement Materials; Circular Economy

I. PLASTIC: POSIBILITY OF USES IN CONCRETE[7]

The paper by Almeshal et al. (2020) presents an innovative approach to solve both issues by using recycled plastic waste as a fine aggregate in cementitious composites such as concrete and mortar. This review gathers and analyzes the results of more than 100 studies to understand how different types of plastics affect the physical, mechanical, and durability properties of concrete. The authors conclude that using recycled plastics offers great potential for sustainable construction.

Plastic waste has become one of the most serious global environmental problems in today's world. Due to its non-biodegradable nature, plastics remain in the environment for hundreds of years, polluting soil, air, and oceans. The global production of plastic materials has crossed 400 million tonnes annually, and only a small percentage is properly recycled.

PROPERTIES EFFECTED –

MECHANICAL PROPERTIES -The mechanical strength of concrete is a key indicator of its performance. The review by Almeshal et al. (2020) shows that mechanical strength generally decreases when natural sand is replaced with plastic waste:[7]

- Compressive Strength: Most studies show a reduction in compressive strength because of weak bonding between plastic and cement paste. A 10–20% plastic replacement can lead to a 15–30% reduction in strength.
- Flexural Strength: Also decreases with higher plastic content, but in small proportions, the concrete can still perform satisfactorily for light construction.
- Tensile Strength: Slightly reduced but offers better flexibility and resistance to cracking. Impact Resistance: Improves due to the elastic nature of plastic particles, which absorb shocks better than natural sand.
- These results indicate that plastic can safely replace up to 10% of sand in concrete without causing major performance issues.

Vol. 12, SPECIAL ISSUE 2, NOVEMBER 2025 DOI: 10.17148/IARJSET/INTEGRATE.2025.12241

PHYSICAL PROPRTIES - Replacing sand with recycled plastic affects several physical properties of concrete

- Density: Concrete made with plastic aggregates is lighter than normal concrete, which is useful in applications where reduced weight is desired, such as precast panels or lightweight blocks.
- Workability: Depending on the shape and texture of the plastic, workability may either increase (for smoother plastics like PET) or decrease (for rougher types like HDPE)
- . Air Content: Plastic particles may introduce more air voids, which slightly lowers compactness but can improve thermal insulation.
- Overall, these properties make plastic-modified concrete ideal for non-structural elements such as pavement blocks, tiles, and walls.

Types of Recycled Plastics Used in Concrete The paper categorizes recycled plastics based on their chemical structure and source. The most common types include: [8]

1. PET (Polyethylene Terephthalate): Found in plastic bottles; offers good strength but decreases bonding with cement
2. HDPE (High-Density Polyethylene): Commonly used in containers and pipes; lightweight and water-resistant.
3. LDPE (Low-Density Polyethylene): Found in films and bags; improves flexibility but reduces compressive strength
4. PP (Polypropylene): Used in ropes and chairs; helps improve impact resistance.
5. PVC (Polyvinyl Chloride): Used in plumbing; adds density but affects cement hydration slightly. Before use, plastics are cleaned, shredded, and sieved into particle sizes comparable to natural sand.

This makes them suitable for use as a partial replacement of fine aggregates.

PVC (POLYVINYL CHLORIDE) – About 40 milion of PVC are produced each year . There is another solution to diminish the attack of wastes against environment via following a special method of recycling, which is the reuse of plastic waste in recycled or lightweight concretes production. This solution may be the best one for those countries have no efficient methods of recycling. Different properties of concrete containing different plastic wastes such as PET, HDPE, PP and PE have now been understood as a result of many experimental tests

The plastic waste was used in concrete in the form of powder, shredded particles or fibers. Although there are relatively large amount of works related to the behavior of concrete containing plastic wastes, few research works deal with the properties of concrete containing PVC aggregate is available in the literature.

Nowadays, there are many varieties of PVC product in use, and because of high daily consumption of this plastic the amount of related waste is large. These wastes become a serious attack for land and water pollutions. The risk of this type of polymer is higher than others such as polyethylene terephthalate (PET) because of the existence of chlorine in its chemical structure, which is about 57%. Therefore there is a serious need for cleaning the environment from the PVC products waste and close the way for any further pollution. One of the important PVC products is the plastic sheets used for secondary roofing and covering walls in buildings. In Suleiman region-Kurdistan, the authors observed a large amount of these sheets have been thrown in the fields outside the city . The source of this waste is because of replacing the old sheets used for secondary roofing and covering walls with new ones for decoration purposes. Other source of these sheets is the extra part of the sheet cut during erection. For each story in a typical residential house there is about ten kilogram of the waste if the sheet is used in both roof and walls. Increasing these wastes is in progress because of the citizen’s demand to rehabilitate their buildings. Therefore, recycling of PVC sheets is quite important and there is a need for the waste stream management[8].

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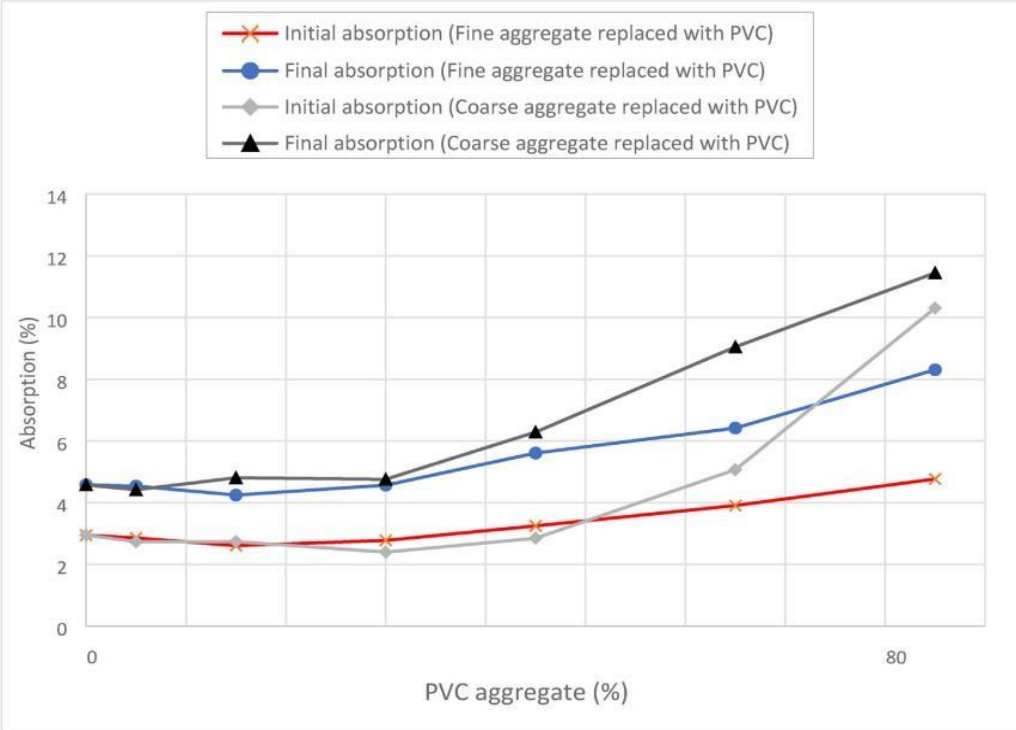

Fig 1 variation of water with PVC aggregate [9]

PLASTIC LIFE CYCLE -There are two ways to retrieve plastic wastes. The first method consists of collecting plastics after they enter the municipal waste stream, while the second method involves the collection of plastics before they enter the municipal waste stream. Most postconsumer wastes (discards from household, commercial and light industrial sources) end up in the municipal waste stream; these plastic wastes are usually very contaminated and are therefore difficult to recycle economically at present. Therefore, the wastes are either disposed of in landfills or incinerated to reduce their volume and to recover their energy content. Conversely, plastic wastes collected outside the municipal waste stream are relatively clean and can be recycled after undergoing some separation and purification processes [9]

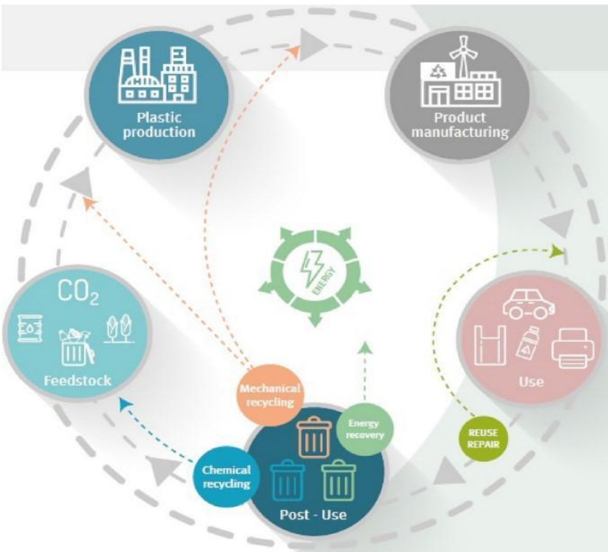

Fig 2 Plastic Life Cycle

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II. RISE HUSK AS AN ALTERNATIVE

Introduction

Rice husk is one of the major agricultural wastes produced in large quantities across the world, especially in rice-growing countries like India, China, and Indonesia. Instead of being discarded or burned—which harms the environment—rice husk can be used as a raw material for making valuable products. This is because rice husk contains a large amount of silica (SiO_2), along with cellulose, hemicellulose, and lignin [1].

The main idea of Soltani et al.'s (2015) paper is to show how rice husk can be processed through physical and chemical treatments to produce advanced materials like silica (SiO_2), silicon carbide (SiC), silicon nitride (Si_3N_4), elemental silicon (Si), magnesium silicide (Mg_2Si), and activated carbon. The paper discusses various production methods and applications in detail.[1]

Composition and Characteristics of Rice Husk

Rice husk is made up of about 20% inorganic materials and 80% organic matter. The inorganic part mainly contains silica, while the organic part is made of cellulose, hemicellulose, and lignin. Because of this composition, rice husk is both light and strong, with a high surface area and porosity. These features make it useful in different industries such as construction, energy, and environmental management.

Applications of Rice Husk and Rice Husk Ash (RHA)[2]

1. Adsorbent: Rice husk ash can remove heavy metals and dyes from wastewater. It is cheaper than activated carbon and works well for removing pollutants like lead, cadmium, and chromium.

2. Cement and Concrete: When used as a partial replacement for cement, RHA improves concrete strength, reduces permeability, and makes concrete more durable. The silica in the ash reacts with calcium hydroxide to form a strong binding gel(C–S–H).

3. Insulation Material: Due to its low thermal conductivity, RHA can be used as an insulating material in furnaces and steel casting to maintain high temperatures.

4. Rubber and Polymer Industry: RHA is used as a filler in rubber and plastic composites to make lightweight and environmentally friendly materials.

5. Energy Production: Rice husk can be burned or gasified to produce heat, electricity, or biofuels. It provides a renewable energy source and helps reduce greenhouse gas emissions.

6. Electronic Materials: High-purity silica and silicon extracted from rice husk can be used in semiconductors and other electronic applications.

Production of Silica from Rice Husk

Silica is the most important product derived from rice husk. The paper discusses different methods for its extraction [2]:

1.Physical Treatment: Controlled burning (at 500–800°C) converts rice husk into amorphous silica. At higher temperatures (>900°C), crystalline silica forms, which is less reactive

2. Chemical Treatment (Pre-treatment): The husk is often boiled or soaked in acids (like HCl, H_2SO_4) to remove metal impurities before burning. This gives pure, white, high-quality silica

3. Post-treatment: After combustion, silica can be purified using alkaline extraction (with NaOH) and then precipitated by adding acid or CO_2 gas

.

4. Hydrothermal Process: This involves heating rice husk with water under high pressure and temperature to dissolve impurities and form nanostructured silica.

Furnace and Reactor Systems

Different types of furnaces are used for controlled combustion of rice husk:

- Rotary Kiln: Converts rice husk to high-reactivity white ash.
- Fluidized Bed Furnace: Ensures uniform combustion and produces ash with low carbon content.
- Cyclonic Furnace: Uses air circulation to increase combustion efficiency.
- Inclined Grate Furnace: Simple design but less efficient in ash separation.

The choice of furnace affects the purity, surface area, and structure of the resulting silica.
Factors Affecting Silica Formation

Temperature: Below 800°C, silica remains amorphous (good for industrial use). Above 900°C, it turns crystalline (less reactive)

Metal Impurities: Elements like potassium and calcium promote crystallization at lower temperatures.
Leaching: Acid or water washing before burning removes impurities and prevents crystallization.

Advanced Materials from Rice Husk

Rice husk can be converted into various silicon-based materials:
1.SiO_2 (Silica): Used in paints, rubber, ceramics, and electronics.
2. SiC (Silicon Carbide): High-temperature material for metal and ceramic composites.
3. Si_3N_4 (Silicon Nitride): Used in high-strength ceramics.
4. Mg_2Si (Magnesium Silicide): Has semiconductor properties.
5. Activated Carbon: Produced through pyrolysis and chemical activation for use in filters and adsorption processes.
Environmental and Economic Importance [1]

Utilizing rice husk adds value to agricultural waste, reduces pollution, and supports sustainable development. It also offers a cheaper alternative for producing high-value materials, especially in developing countries. Using rice husk for material production reduces landfill waste, cuts down greenhouse gas emissions, and conserves natural resources.

III. FLY ASH

Fly ash particles are considered to be highly contaminating, due to their enrichment in potentially toxic trace elements which condense from the flue gas. Research on the potential applications of these wastes has environmental relevance, in addition to industrial interest. Most of the fly ash which is produced is disposed of as landfill, a practice which is under examination for environmental concerns. Disposal of fly ash will soon be too costly – if not forbidden. Considerable research is being conducted worldwide on the use of waste materials in order to avert an increasing toxic threat to the environment, or to streamline present waste disposal techniques by making them more affordable. It follows that an economically viable solution to this problem should include utilization of waste materials for new products rather than land disposal

PROPERTIES –

PHYSICAL PROPERTIES - The physical properties of fly ash depend on the nature of coal; mineral matter chemistry and mineralogy, furnace design, furnace operation and method of particulate control; such as Sulphur Oxide (SOx) and Nitrogen Oxide (NOx) control technologies (French et al. 2007). Fly ash particles are generally spherical in shape and ranging from 0.5 µm to 100 µm. A number of studies have been done by various researchers to study on physical properties of fly ash (table 1). These properties influence the properties of the final product such as workability, pumpability, water requirement as well as permeability.

Property	*Maher & Balaguru (1993)*	*Mitash N (2007)*	*Huang et a (1995)*	*Muhardi et al (2010)*
Specific gravity	*2.54*	*1.9-2.55*	*2.06*	*2.3*
Moisture content	*13.60%*		*0.53%*	*19.75%*
Fineness			*13.80% in No. 325*	*0.6 - 0.001 mm*
LOI			*7.5*	
Maximum dry density	*1.65 g/cm^3*	*0.9-1.6 g/ cm^3*		*1.53 g / cm^{3}cc*
uniformity coefficient	*2.5*	*3.1-10.7*		
liquid limit	*16.8*			
permeability	*0.9 x 10^{-5} cm/s*	*10^{-5} - 10^{-3} cm/s*		*4.87 x 10^{-7} cm/s*
angle of internal friction		*30°- 40°*		*23°-41°*
cohesion		*Negligible*		*3-34 kPa*
compression index		*0.05-0.4*		*0.15*
coefficient of consolidation				*0.1 - 0.5 m^2/year*

Table 1 physical properties of fly ash

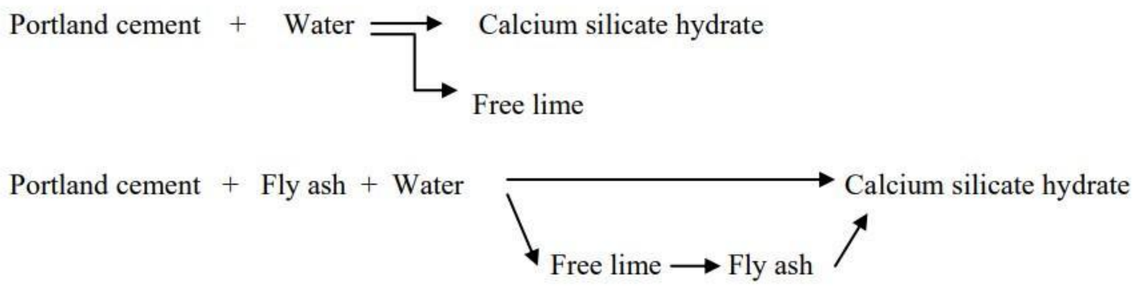
CHEMICAL PROPETIES –

It can be seen that chemical compounds of fly ash is almost the same as in Portland cement (Table 2). Major proportion of fly ash; Silica Oxide (SiO), Aluminum Oxide (Al2O3), Iron Oxide (Fe2O3) and CaO, is the same as major compounds found in cement. However the proportion of each compound differs significantly comparing fly ash (class F & class C) and Portland cement and natural pozzolans (class N)

Chemical compound	*Pozzolan type*			*Cement*
	Class F	*Class C*	*Class N*	
SiO	*54.90*	*39.90*	*58.20*	*22.60*
Al_2O_3	*25.80*	*16.70*	*18.40*	*4.30*
Fe_2O_3	*6.90*	*5.80*	*9.30*	*2.40*
CaO	*8.70*	*24.30*	*3.30*	*64.40*
MgO	*1.80*	*4.60*	*3.90*	*2.10*
SO_3	*0.60*	*3.30*	*1.10*	*2.30*
Na_2O & K_2O	*0.60*	*1.30*	*1.10*	*0.60*

Table 2 chemical properties of fly ash [3]

It can be seen that Portland cement is rich in lime (CaO) while fly ash is low. Fly ash is high in reactive silicates while Portland cement has smaller amounts. With these chemical properties it is recommended to use fly ash with Portland cement since the pozzolanic activity of fly ash causes the fly ash to combine with free lime to produce the same cementations compounds formed by the hydration of Portland cement as shown in Figure 1 (Headwaters 2005).



Kayali (2005) produced high performance fly ash bricks, using fly ash, water & chemical additives such as plasticizer, Carboxymethyl Cellulose (CMC) and CaCl2 in small quantities. Addition of CaCl2 as an admixture would help to accelerate the curing process significantly however it would increase corrosion of any metallic object which may be in contact with these bricks. Raw bricks were cured for three days before firing. These fly ash bricks were about 28% lighter than clay bricks and possessed compressive strength higher than 40MPa.[4]

Various methods have been used by past researchers in making fly ash cement composites. Ashby (1990) explains three ways of incorporating fly ash in cement: as a part of cementitious material, or as a fine aggregate or a combination of cementitious material and fine aggregate. The percentage of fly ash in concrete can be as high as 40% of concrete mix and using chemical admixture can improve curing time of fly ash concrete. Concrete containing fly ash and chemical admixture absorb less water than plain concrete.[12]

Maher & Balaguru (1993) investigated the usability of flowable high volume fly ash cement composite. Cylindrical specimens were casted using plastic moulds and compaction was achieved using a table vibrator. Although the mixing and casting method was bit similar to that of clay bricks, they adopted a different curing procedure. They have used humid rooms maintained at 100% relative humidity and 22oC for three days before de-moulding as well as until testing. The specimens were tested for 3, 7, 28, 56, 90 and 180 day compressive strength. They reported that a sand-cement ratio of 15:1 and w/c ratio of 0.3 seem to provide the best result for compressive strength of 21MPa at 180 days. [4]

As reviewed in the past literature, black coal fly ash was mainly used by many researches since it contains fewer impurities compared to brown coal fly ash. Brown coal fly ash has the same potential as in black coal, if it is used in a proper manner. Also the disposal percentage of brown coal fly ash can be reduced, if it is utilized in a better purpose such as manufacturing building materials. Therefore it is necessary to focus on new researches to develop methods of incorporating brown coal fly ash in building material products. This will eventually minimize the environmental pollution caused by disposal of brown coal fly ash. [3]

IV. RUBBER

In India, over 15 million waste tires are generated annually. Not only are these tire mounds eyesores, they are also environmental and health hazards. The little pools of water retained by whole waste tires create an ideal breeding ground for mosquitoes. Aside from the persistent annoyance, mosquitoes have been shown to spread various dangerous diseases. Equally hazardous are tire fires, which pollute the air with large quantities of carbon smoke, hydrocarbons, and residue. These fires are virtually impossible to extinguish once started. Currently, the only large scale methods to use waste tires are through burning for electric power generation, production of cement in cement kilns, energy to run pulp and paper mills, and recycling at tires-to-energy facilities. In 1990, the Environmental Protection Agency (EPA) estimated that out of the 242 million waste tires generated that year, 78% of the tires were either stockpiled, a land filled, or illegally dumped. While some states burn waste tires this is only a temporary solution because of the tires, in many cases, tend to float back up to the surface. Land filling waste tires has also become more and more expensive as landfill space has decreased. [5]

Hazards of Tyre Waste - 1) This waste tires are produced carbon by burning process. 2) This amount of tyres is very large manner so it becomes dangerous as well as uncomfortable to placing, because of Land problems to our country. 3) Potentially harmful substances were found exposed to highly acidic solutions. 4) Aside from the persistent annoyance, mosquitoes have been shown to spread various dangerous diseases. 5) Equally hazardous are tyre fires, which pollute the air with large quantities of carbon smoke, hydrocarbons, and residue. 6) Not only are this tyre mounds eyesores, they are also environmental and health hazards. The little pools of water retained by whole waste tyres create an ideal breeding ground for mosquitoes. 7) These fires are virtually impossible to extinguish once started. [5]

Crumb Rubber Modified Bitumen (CRMB) –

Crumb rubber is also used to modify bitumen in an appropriate manner, so that its resistance to temperature, water etc. is better. This modified bitumen is one of the important construction materials for flexible Road pavement. The rubber waste/crumb rubber modified bitumen show better properties for road construction.[6]

Preparations to make Crumb Rubber Modified Bitumen blend-[6]

The studies on the behavior and binding property promoted a study on the preparation of rubber waste bitumen blend. Its bituminous properties are found. These properties are compared with Normal Bitumen. Then its suitability as a blend for road construction is investigated. Scrap tire rubber can be incorporated into asphalt paving mixes using two different methods, which are referred to as the wet process and the dry process. In the wet process, crumb rubber acts as an asphalt cement modifier, while in the dry process, granulated or ground rubber and/or crumb rubber is used as a portion of the fine aggregate. CRMB is produced by the so-called wet process in which crumb rubber is added to hot bitumen of temperature around 150 -160 degree C and the mixture is agitated mechanically until there is a “reaction” between the bitumen and crumb rubber. The “reaction” is not a chemical process but rather a diffusion process that includes the physical absorption of aromatic oils from the bitumen into the polymer chain of the rubber. The rubber particles swell as they absorb oils, which cause the viscosity of the CRMB to increase during the first hour or so. After the “reaction” and associated swelling is over the viscosity of the blend levels off.

Penetration test [6]

It measures the hardness or softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in 5 seconds. BIS had standardized the equipment and test procedure. The penetrometer consists of a needle assembly with a total weight of 100g and a device for releasing and locking in any position. The bitumen is softened to a pouring consistency, stirred thoroughly and poured into containers at a depth at least 15 mm in excess of the expected penetration. The test should be conducted at a specified temperature of 25o C. It may be noted that penetration value is largely influenced by any inaccuracy with regards to pouring temperature, the size of the needle, weight placed on the needle and the test temperature. A grade of 40/50 bitumen means the penetration value is in the range 40 to 50 at standard test conditions. In hot climates, a lower penetration grade is preferred.

% Of CRMB	**Reading**	**Trial**			**Average. Value In mm**
		1	**2**	**3**	
0% of CRMB	Initial	0	0	0	**69**
	Final	64	69	75	
Penetration Value		**64**	**69**	**75**	
8% of CRMB	Initial	0	0	0	**49.33**
	Final	44	48	56	
Penetration Value		**44**	**48**	**56**	
10% of CRMB	Initial	0	0	0	**38.67**
	Final	33	37	47	
Penetration Value		**33**	**37**	**47**	
12% of CRMB	Initial	0	0	0	**19.67**
	Final	19	20	20	
Penetration Value		**19**	**20**	**20**	
14% of CRMB	Initial	0	0	0	**14.33**
	Final	14	14	15	
Penetration Value		**14**	**14**	**15**	

TABLE 3 PENETRATION RESULT

IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

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Result [11]

Penetration Test were done for normal bitumen and modified bitumen with 0%, 8%, 10%, 12%, and 14% of rubber waste content. The result was shown in Table 2. From the result of the test, the penetration value for normal bitumen was 69 mm. Penetration value decreased with the increased amount of the rubber waste added. Lower penetration value making harder grade of asphalt, giving additional strength to the road and reduces water damage.

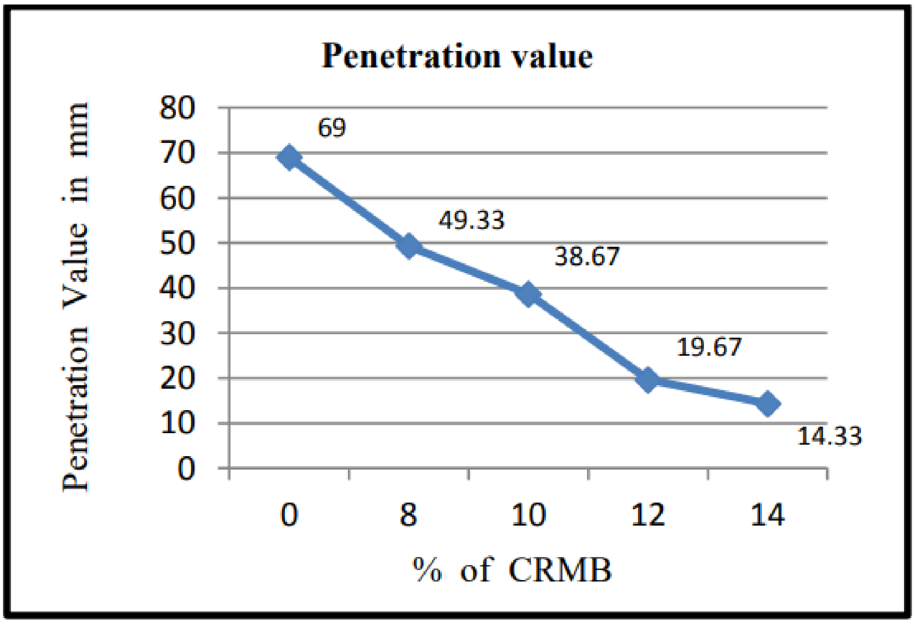

FIG 3 PRNERTRATION RESULT GRAPH

V. CONCLUSION

The review emphasizes the growing importance of reusing industrial and agricultural waste materials such as fly ash, rice husk ash, recycled plastic, and rubber in civil engineering to achieve sustainability and environmental protection. Fly ash and rice husk ash, rich in silica and alumina, serve as effective supplementary cementitious materials that improve the strength, durability, and workability of concrete while reducing cement consumption and carbon emissions. Recycled plastics, when used as partial replacements for fine aggregates, reduce concrete density and enhance impact resistance, making them suitable for non-structural applications such as paver blocks, tiles, and lightweight panels. Similarly, crumb rubber derived from waste tires enhances the performance of bituminous pavements by improving flexibility, resistance to rutting, and temperature stability.

The combined utilization of these materials not only minimizes environmental hazards caused by waste disposal but also promotes a circular economy within the construction industry. Despite certain limitations in mechanical performance and long-term durability, these waste-based materials present promising solutions for eco-friendly and cost-effective construction. Further research and standardization efforts are essential to fully realize their potential in large-scale civil infrastructure projects.

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