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Partial Replacement of Aggregates with Kernel Shells and Foundry Sand in Bitumen

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***Abstract*—Waste Foundry Sand (WFS) is increasingly utilized in the seafood processing sector due to rising waste disposal costs and environmental concerns, despite large quantities still ending up in landfills globally, including in India and the UK. Crushed palm kernel shell (CPKS) is an effective partial replacement for coarse or fine aggregates in asphalt concrete, with varying substitution levels based on traffic intensity: up to 80% for light traffic, 60% for moderate traffic, and 20% for heavy traffic. Additionally, palm kernel shells can replace up to 80% of fine aggregate across traffic conditions, offering a cost-effective, eco-friendly alternative that reduces reliance on natural aggregates.**

This research evaluates 13 combination ratios using bitumen VG-30 as a binder. WFS was substituted for fine aggregates at 0%, 8%, 16%, 24%, 32%, and 40%, while palm kernel hulls were similarly substituted at the same percentages. For analysis of these aggregate tests like as impact value, crushing strength and abrasion test, Marshall stability test and Indirect dry and wet tensile strength test is performed. After analysis of test results recommended mix will be known which are beneficial for the further studies.

***Index Terms*—Palm Kernel Shell, Coarse aggregate, Marshal Stability, Innovative filler, Sustainable pavement material, Functional pavement.**

I. INTRODUCTION

Modern road construction integrates advanced materials, sustainable practices, and innovative techniques to build durable and efficient infrastructure. It emphasizes eco-friendly solutions, such as using industrial byproducts like Waste Foundry Sand and palm kernel shells, to reduce environmental impact and conserve natural resources. Technologies like asphalt recycling, precision equipment, and improved bituminous mixes enhance road quality and longevity. These advancements cater to growing traffic demands while minimizing construction costs and ecological footprints.

Waste Foundry Sand (WFS), a byproduct of ferrous and non-ferrous industries, can be effectively reused in road construction when industrial waste is incorporated. Producing 9–10 million tonnes annually, WFS reduces energy usage and stress on resources. Known as "lost wool," it can be reused even after being discarded by manufacturers. Asphalt and bituminous materials are widely used in road construction for their low cost, good adhesion, and water resistance. Asphalt, a black or viscous material, comprises carbon disulfide-dissolved hydrocarbons derived from oils or bitumen. Tar, produced from the decomposition and burning of materials like stone and wood, has a higher temperature threshold than asphalt, while pitch is oil-soluble. Bitumen, a residue from petroleum refining, is processed through techniques like vertical flow and solvent extraction to create various asphalt types and essential products, depending on the crude’s properties.

II. LITERATURE REVIEW

Recent research emphasizes the significant potential of industrial byproducts like Waste Foundry Sand (WFS), Fly Ash (FA), and Palm Kernel Shells (PKS) in promoting sustainable construction practices. Krishnapriya Sankarapandian et al. (2024) demonstrated that replacing up to 25% of M Sand with WFS in concrete enhances compressive strength and durability, offering a feasible alternative to natural sand. Similarly, Akhila Sheshadri et al. (2024) showed that WFS can replace 15%-20% of river sand in pavement-quality concretes without compromising mechanical properties, supporting waste utilization in road construction. Padavala Siva

Shanmukha Anjaneya Babu et al. (2024) explored lightweight concrete using FA and PKS, achieving optimal strength with 25% FA and 10% PKS replacements, along with hybrid fibers, suitable for cost-effective and resource-efficient housing.

Other studies highlight the versatility of PKS and coconut shells in paver blocks, where their inclusion improves compressive strength, water absorption, and durability, demonstrating their potential as eco-friendly alternatives. Rahul Kumar and Amit Richhariya (2023) observed improved mechanical properties in concrete paver blocks with up to 5% WFS, while higher replacements led to strength reductions. Additionally, advancements in subgrade pavement applications were noted by Avinash Bhardwaj and R. K. Sharma (2022), who stabilized clayey soils with WFS, molasses, and lime, improving geotechnical properties and reducing pavement thickness. Studies on fired clay bricks by Noor Amira Sarani et al. (2023) found that up to 5% PKS enhances thermal conductivity and sustainability. These findings collectively underline the potential of industrial byproducts to reduce dependence on natural resources, lower construction costs, manage waste effectively, and address environmental challenges in the construction industry. Research by A. A. Shuaibu et al. (2021) showed that incorporating 30% WFS in bituminous concrete achieved maximum stability, meeting road construction standards.

Ali Mohammed Babalghaith et al. (2020) demonstrated that 50% replacement of palm oil clinker (POC) in stone mastic asphalt (SMA) improves performance, while G. Mounika and B.H.S. Sai Prasanth (2020) found sugarcane molasses to be an effective sustainable binder enhancing stability. Guilian Zou et al. (2020) revealed that using construction and demolition waste (CDW) in emulsified asphalt mixtures improves water resistance and mechanical properties. Jinyan Shi et al. (2020) explored alkali-activated slag mortars (FSAM) with GGBS and ACBFS, showing superior mechanical strength and temperature resistance. Kalpana et al. (2020) reported that cast iron waste strengthens bitumen mixtures. The study examined various properties of bitumen mixed with different percentages (4%, 8%, and 10%) of cast iron waste. Results showed that while the softening point decreases compared to normal bitumen, penetration increases with the addition of cast iron. Ductility remains constant, indicating no significant change, while flow viscosity increases. Lizasoain-Arteaga Esther et al. (2020) assessed steel slag's environmental benefits as an aggregate replacement. The analysis led to the following conclusions: LCA findings are strongly influenced by the slag absorption rate, which also increases the binder concentration and overall moisture content of the mixture. Paluri Yeswanth et al. (2020) noted that fine recycled asphalt (FRAP) with steel fibers enhances concrete strength up to 75% replacement. Ramadhansyah et al. (2020) showed that coconut shell charcoal ash improves asphalt strength, while S. Eswar et al. (2020) demonstrated the potential of polyethylene (LDPE) as a durable asphalt substitute. T.B. Vishnu et al. (2020) highlighted effective recycling of municipal waste for sustainable pavement construction. Thiagarajan et al. (2020) studied blending bituminous coal with palm kernel shells for efficient co-gasification, offering energy and environmental benefits.

D. Movilla-Quesada et al. (2019) studied the dry mixing procedure of plastic waste in asphalt, finding that polymer-coated aggregates enhance stiffness and compressive strength, making the mix suitable for warm climates. P.P.O.L. Dyer et al. (2019) showed that waste foundry sand (WFS) has physical and chemical properties similar to conventional sand, reducing costs and environmental impact while meeting asphalt performance standards. Ujjwal Gupta and Deepak Juneja (2019) highlighted the potential of eco-friendly materials like candy syrup cubes for durable blacktop layers. Gagandeep et al. (2018) proposed using surplus plastic for road construction, addressing waste disposal and road quality issues. Raja Mistry et al. (2017) demonstrated that fly ash and rice husk ash improve asphalt's resistance to deformation and reduce production costs. Ratnasamy Muniandy et al. (2017) found that ceramic waste aggregates enhance asphalt stability but require proper processing for compaction efficiency.

III. MATERIALS

Bitumen: Bitumen is a viscous, black organic liquid composed of polycyclic aromatic hydrocarbons, soluble in carbon disulfide. It has a molasses-like taste at room temperature and a high boiling point of

525°C (997°F). Bitumen is a low-grade residue left after crude oil refining. In British English, it refers to a mixture of aggregate and bitumen, while in Australian English, it commonly denotes road surfaces. Asphalt, derived from bitumen, is used in road construction, and bitumen is also used in applications like flat roof coatings and asphalt putty.

Coarse Aggregates: Coarse aggregates are larger particles, typically ranging from 4.75 mm to 75 mm in size, used in construction for producing concrete and asphalt. They provide strength, stability, and durability to the structure.

Fine Aggregates: Fine aggregates consist of smaller particles, generally less than 4.75 mm in size, such as sand. They are essential for filling voids between coarse aggregates in concrete and contributing to the mixture's workability.

Fig. 1 Palm kernel shells

Fig. 2 Foundry Sand

Waste Foundry Sand: Waste foundry sand is a byproduct from metal casting processes, composed of fine sand mixed with binders. It can be recycled into construction materials like concrete and is valued for its properties that improve workability and strength.

Palm Kernel Shell: Palm kernel shell is a natural, lightweight material derived from the seed of the oil palm fruit. It is often used as an aggregate in concrete, offering environmental benefits and reducing the overall weight of the concrete mix.

III. METHODOLOGY

Detailed laboratory tests are performed on asphalt and aggregate are discussed in this section. Include information on additional elements, such as waste and prime harvest outcomes at 0%, 8%, 10%, 24%, 32, and 40%, sequentially, and palm kernel harvest at 0%, 8%, 10%, 24%, 32, and 40%.

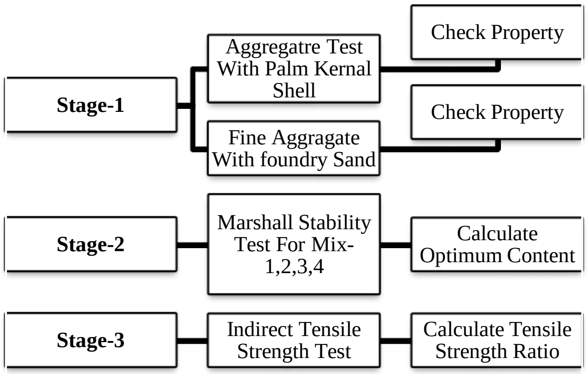

Table 1 Chemical compositions of used foundry sand

Constituents	Value (%)
SiO2	87.91
Al2O3	4.70
Fe2O3	0.94
Cao	0.14
MgO	0.30
SO3	0.09
Na2O3	0.19
K2O	0.25
TiO2	0.15
SrO	0.03

Table 2 Different type of Bitumen test

Description	Results
Penetration (mm)	70
Ductility (cm)	45
Viscosity (Sec)	89
Flash Point (°C)	176
Fire Point (°C)	245
Softening Point (°C)	53
Specific Gravity	1.02

Table 3 Mix with Percentage Replacement

Mix	% Bitumen	% Coarse Aggregate	% Fine Aggregate	Palm Kernel Shell	Foundry Sand
STD Mix	100%	100%	100%	0%	0%
Mix -1	100%	92%	92%	8%	8%
Mix -2	100%	84%	84%	16%	16%
Mix -3	100%	76%	76%	24%	24%
Mix -4	100%	68%	68%	32%	32%
Mix -5	100%	60%	60%	40%	40%

IV. RESULTS AND DISCUSSION

This section presents the results obtained from the experimental investigations and their analysis. The findings are systematically organized to provide clarity and insight into the study's objectives.

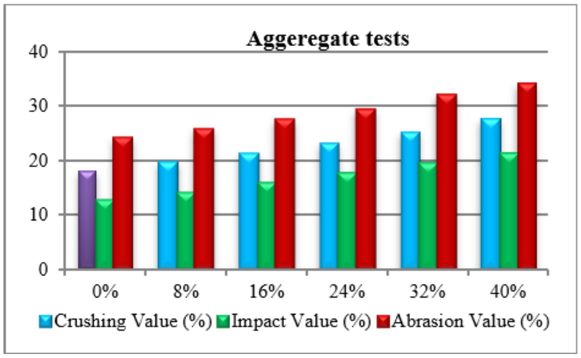

Fig. 3 Crushing, Impact and Abrasion test of varying of aggregate replacement

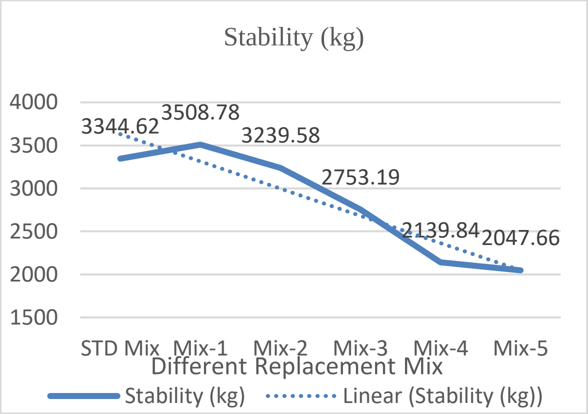

Fig. 4 Stability in different replacement mixes

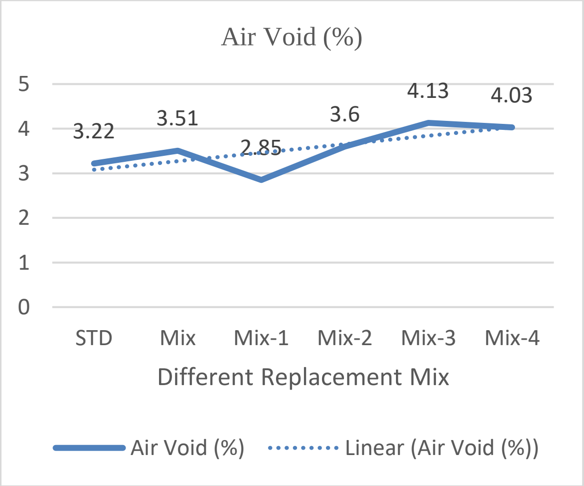

Fig. 5 Air Voids in different replacement mixes

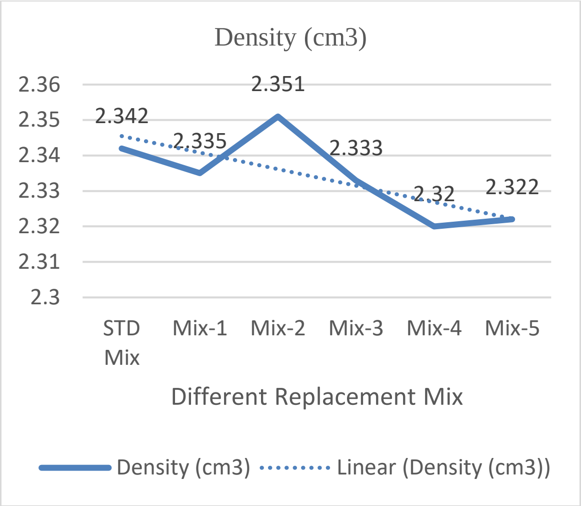

Fig. 6 Density in different replacement mixes

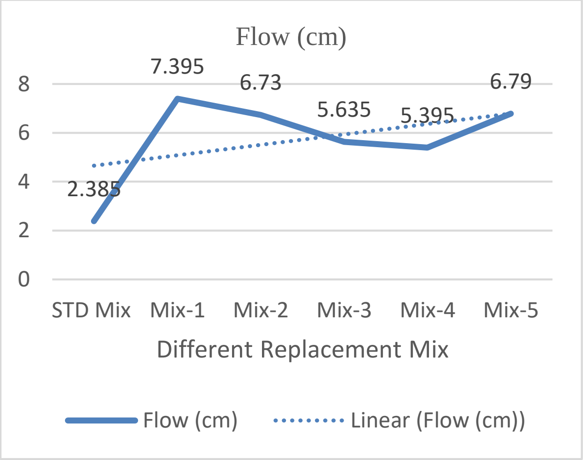

Fig. 7 Flow in different replacement mixes

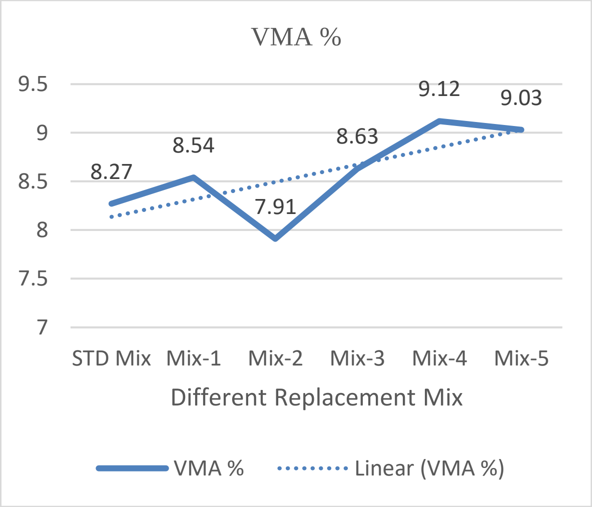

Fig. 8 VMA in different replacement mixes

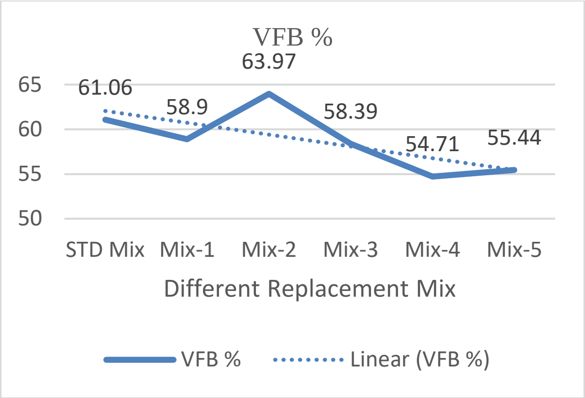

Fig. 9 VFB in different replacement mixes

Indirect Tensile strength (Dry & Wet) Test Result

The Indirect Tensile Strength (ITS) test measures the tensile strength of cylindrical specimens under compressive loading, evaluated in both dry and wet conditions. Results indicate the material's resistance to cracking and water-induced deterioration, with higher ITS values signifying better performance.

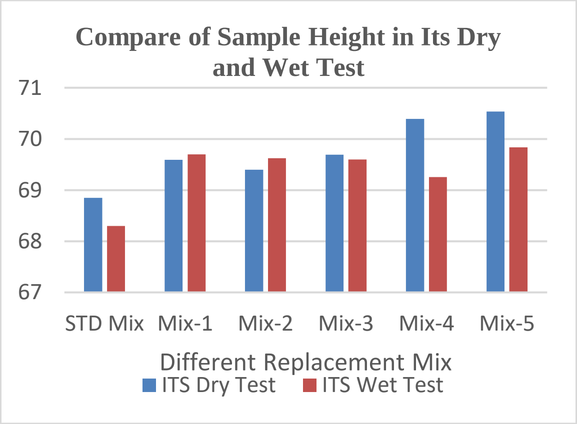

Fig. 10 Compare of Sample Height in ITS Dry and Wet Test

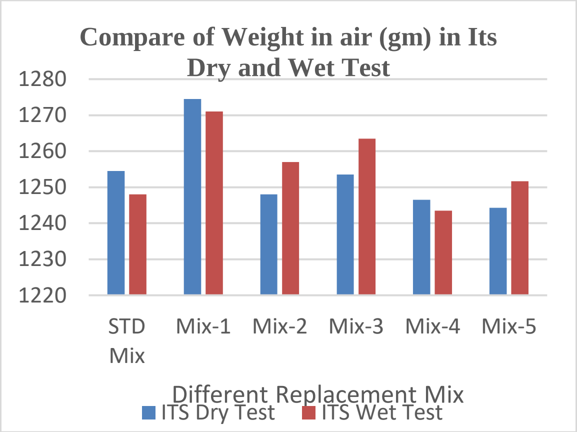

Fig. 11 Compare of Weight in air (gm) in ITS Dry and Wet Test

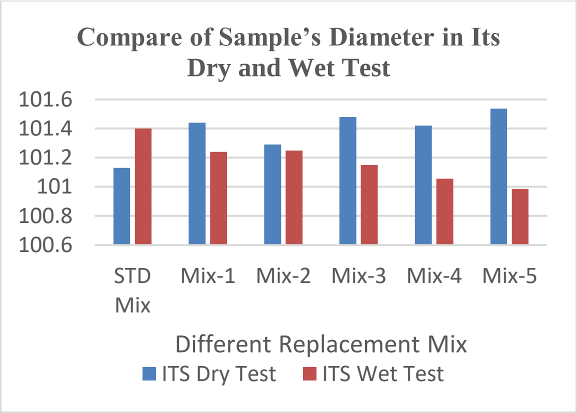

Fig. 12 Compare of Sample's Diameter in ITS Dry and Wet Test

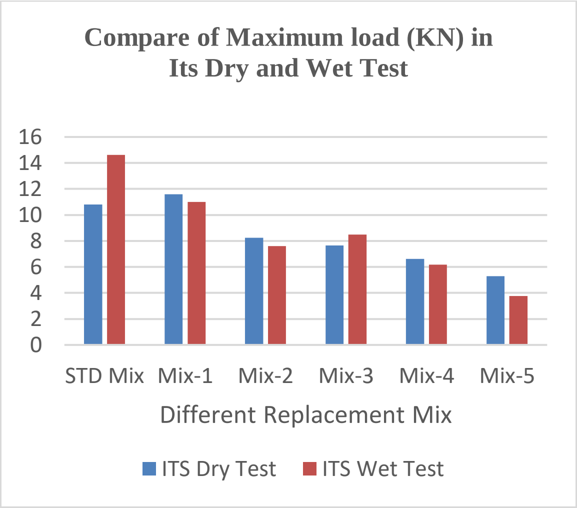

Fig. 13 Compare of Maximum load (KN) in ITS Dry and Wet Test

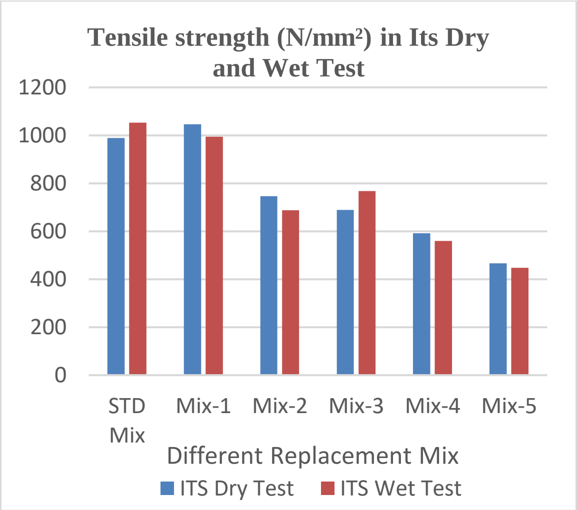

Fig. 14 Compare of Tensile strength (N/mm²) in ITS Dry and Wet Test

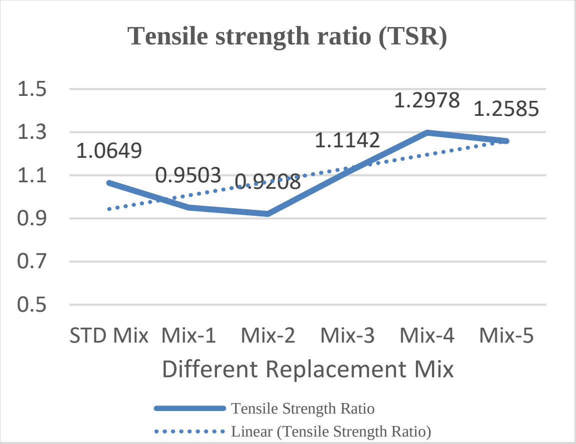

Fig. 15 Tensile strength ratio (TSR)

V. CONCLUSIONS

Here are the inferred conclusions for each mix.

Aggregate tests

- The optimum crushing value of natural coarse aggregates was 9.4 percent. It was discovered that replacing palm kernel shell increases the crushing value. Upto 32% the crushing value was found to be satisfactory as 25%.
- The optimum impact value of natural coarse aggregates was 17.74 percent. It was discovered that replacing palm kernel shell increases the impact value. Upto 32% the impact value was found to be satisfactory as 19.2.
- The optimum abrasion value of natural coarse aggregates was 25.14 percent. It was discovered that replacing palm kernel shell increases the abrasion value. Upto 32% the abrasion value was found to be satisfactory as 31.8%.

Marshal Stability Test

- Mix-1, Mix-2 and Mix-3 should be prioritized for further testing and use, as they provide a balance of stability, durability, and resistance to deformation.
- Mixes with high air voids (e.g., Mix-4 and Mix-5) should be re-evaluated for material selection and compaction techniques to enhance performance.

Indirect Tensile strength (Dry & Wet) Test

- For applications in environments prone to moisture exposure, Mix-3, Mix-4 and Mix-5 are highly recommended due to their excellent tensile strength ratio.
- Mix-1 and Mix-2 may need modifications or additional treatment to improve their moisture resistance for practical use.

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