USE OF IRON ORE TAILINGS IN POTHOLE PATCHING MIXTURES AS A REPLACEMENT FOR CONVENTIONAL AGGREGATES

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Abstract

A pothole is a depression in the road's surface, often made of asphalt, where the pavement has been damaged by driving. Typically, vehicles travelling over the damaged region and water in the underlying soil structure are to blame. Traffic then wears down and cracks the inadequately supported asphalt surface in the affected region after water affects the underlying soil. In order to produce a hole in the pavement, continued driving activity ejects both the asphalt and the underlying soil layer. As iron ore concentrate is beneficiated, a type of solid waste called iron ore tailings (IOTs) is created. IOTs are one of the most prevalent solid wastes in the world among all types of mining solid waste because of their huge output and low usage ratio.
These iron ore tailings can be utilised in pothole filling mixes in place of traditional aggregates entirely. The creation of pothole filling solutions from iron ore tailings will aid in the extensive usage of these wastes. The Marshall stability test, which involves preparing the mould and assessing the mold's strength after 24 hours of setting time, has been used to determine the ideal binder concentration. According to the test results, the ideal binder percentage is 5 percent of the aggregates' total weight, or 1200 grammes, of which aggregates were used. Kerosene and bitumen were mixed in a proportion of 30% to 70% to create the cutback bitumen.

Keywords: Tensile Strength Ratio, Optimal Binder Content, Iron Ore Tailing, Cutback, and Zycotherm

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1. Introduction

A pothole is a tiny region of distress in an asphalt-surfaced pavement brought on by the erosion of the base course and asphalt surface. Potholes are depressions in the road surface that are often constructed of asphalt where debris has been removed by driving water into the underlying soil structure and traffic in the affected region. The underlying soil is initially weakened by water.(Shettima et al., 2016) As a result of traffic fatigue, the asphalt surface in the affected region is then damaged. Two variables are the main contributors to pothole formation. Two of them are shoddy workmanship and inconsistent design. When there is a lot of traffic in certain regions, the asphalt deteriorates, materials are scraped from the surface, and potholes are left in their wake.(Obaidi et al., 2017) Two further elements that contribute to the creation of potholes are the seepage of water through cracks and freezing temperatures. As water freezes, it pushes down the stratum and top layer of asphalt, weakening the surfaces that support the road surface and creating a zone of weak stresses.(Khalid & Monney, 2009)

As a vehicle drives over a surface layer, it disintegrates, creating a pothole. As a result, materials break off and spill onto the nearby pavement. Potholes are to blame for extended travel times, wasted fuel, and backed-up traffic. In the end, this adds to air pollution, which harms people's health and results in other serious problems. Also, the existence of these potholes causes a lot of accidents.(Dong et al., 2014; Sainz, 2016; Yang et al., 2015)

There are four primary causes for sinkhole formation:

1. A lack of road traction during the snowy or melting seasons without local failure
2. A lack of water flow
3. Operating and simulation channels failing (holes and drain casings)
4. Unattended flaws and fissures in paved roadways that are closed, allowing moisture to enter and endangering the structural integrity of the pavement.

Iron ore tailings (IOTs) are a form of solid waste produced during the beneficiation of iron ore concentrate.(Thanaya et al., 2014) IOTs create a lot but utilise very little, making them among the most distributed solid wastes in the world among all forms of mining solid waste. Iron, the fourth most frequent element, makes up around 5% of the Earth's crust. Since roughly 4,000 years ago, iron, which is usually found as ore, has been used to create tools and weapons. Because iron ore is essential to the creation of steel, it is difficult to imagine modern life without it. The majority of the world's iron ore deposits are found in South Africa, Australia, Brazil, Canada, India, China, and Europe.

The creation of iron ore concentrates from the iron ore in raw form results in the formation of tailing in the form of fines and coarse particles, accounting for a total of 20–40% of the weight of iron ore used in raw form. This is a significant by-product that must be disposed of or used in some other way to prevent pollution and environmental harm.(Dax Patel et al., 2018) If not used for any purpose, it must be disposed of at a location, which has a number of negative effects, including polluting the groundwater under the disposal site, leaving the region desolate, and prohibiting further agricultural activities since it renders the soil impermeable and less fruitful.(Dong et al., 2014)

1.1 Problem statement

1. Iron ore tailings are one of the most frequently generated wastes in the world. The following is a list of the most common questions we get asked about our services.
2. These iron ore tailings can totally replace conventional aggregates in pothole repair mixtures. Iron ore tailings may be used to make pothole repair mixes in huge amounts.
3. All around the world, there are a lot of potholes. to employ iron ore tailings in place of other materials to fill potholes.
4. These iron ore tailings can completely replace conventional aggregates in pothole filling combinations. Making pothole-filling solutions from iron ore tailings will allow for the major use of these wastes.

1.2 Research objectives

- Using iron ore tailings as a component in pothole repair solutions requires a petrographic analysis.
- Iron ore tailings are used in place of traditional aggregates in pothole filling mixes with antistripping chemicals.
- Evaluation of iron ore tailings and natural aggregate pothole repair mixes in a lab

2. Tested and applied materials

In this experiment, Cutback Bitumen, Coarse Aggregate, Fine Aggregate, Iron Ore Tailings, and Zycotherm were used.

2.1. Aggregates values

The aggregates were sourced from the L.G. Blue Metal crusher in Tamil Nadu using the aggregate's combined gradation percentage passing formula. According to Indian Standards, the amount of aggregates was precisely measured to within 0.1 grammes: 2386(Part 1)-1963.(Yang et al., 2015)

2.2 Cutback

Bitumen is diluted with petroleum hydrocarbon to create the petroleum product known as "cutback bitumen" (Kerosene). Viscosity must be decreased to enhance bitumen's penetration into asphalt surfaces. Kerosene and bitumen were mixed in a proportion of 30% to 70% to create the cutback bitumen.(Obaidi et al., 2017)

2.3 Tailings of Iron Ore

Because of their enormous output and low utilisation ratio, IOTs are among the most common solid wastes in the world among all categories of mining solid waste. From the Kudremukh, iron ore tailings were transported.(Liu et al., 2018) They were sieved in accordance with the aggregate sieve sizes.

Table -1: Iron Ore Tailings Characteristics

S. NO.	**Properties**	**Values**
1	Fines (clay and silt) %	6.5
2	Sand Content	69.50
3	Gravel Content	24.00
4	Specific Gravity	2.65
5	Minimum dry density	1685.00 kg/m3
6	Maximum dry density	1860.00 kg/m3
7	Effective grain size D10	0.13mm
8	D60	2.67mm
9	D30	0.70mm
10	Coefficient of Uniformity, Cu	20.54
11	Coefficient of Curvature, CC	1.41

2.4 Zycotherm

The newest warm mix asphalt antistrip ingredient is called ZycoTherm (WMA). It functions with all categories of aggregate. Increased bitumen adhesion is made possible by it. Bituminous blends use Zycotherm, a nano organosilane component that has no smell. Zycotherm ensures that bitumen is thoroughly covered at low temperatures and improves chemical bonding for longer moisture resistance.(Leonardi et al., 2018)

3. Research Methodology

The samples must go through several tests, starting with a Marshal stability test to determine the ideal binder content.

3.1. Examining aggregates

The aggregates must undergo the following examination.

- Particular Gravity
- Water Solubility
- Crushing and Abrasion Value
- Extended Index
- Flakiness
- Weight Density

3.2 Cutback Test

- The list of tests done on Cutback is as follows:
- Test of Penetration
- Specific Gravity at Softening Point
- Difficulty Test
- Fire & Flash
- test for viscosity

3.3 Multiple Specimen tests

The tests done on the mix specimen are listed below.

- Marshal Stability Test

- Adhesion Test
- Cohesion Test
- Indirect Tensile Strength Test

3.3.1 Design of Marshall Mix

There are six fundamental phases in the Marshall mix design method:

- choosing aggregates
- choosing a binder for asphalt
- preparing a sample (including compaction)
- Using the Marshall Stability Test Equipment to determine stability
- Voids and density calculations
- best choice of asphalt binder ingredients

3.3.1.1 Blend Design

Table -2: Marshall Mix Proportions

Optimum binder content by weight mix	5 % by weight of mix	60 Gms
(9.5mm – 4.75 mm)	40 % by weight of Aggregate	480 Gms
(4.75mm – 2.36 mm)	35 % by weight of Aggregate	420 Gms
(2.36mm – 1.18 mm)	20 % by weight of Aggregate	240 Gms
(1.18mm – 0.075mm)	5% by weight of Aggregate	60 Gms

The following are the results of a survey conducted by the National Institute of Standards and Technology (NIST) on the use of the standardised test in the United States.

Table -3: Blended Gradation of Aggregate

IS Sieve (mm)	Job Mix formula combined gradation Percentage passing	MORTH Specified Limits table 500-10
19	100	100
13.2	99.08	90-100
9.5	85.99	70-88
4.75	58.74	53-71
2.36	46.47	42-58
1.18	38.43	34-48
0.6	31.43	26-38
0.3	22.37	18-28
0.15	15.52	12-20
0.075	6.42	6.42

Table 3 depicts the job mix formula of combined gradation percentage passing as per MORTH (table 500-10) specified limits

I Within the lab, When preparing samples, we should have an idea of the range in which the ideal binder content will fall. We should then mix a specific number of samples with three different blends, thoroughly combine the aggregates and the selected amount of bitumen content, and then bake the mixture at 135 C for 24 hours. The mixture may be removed the next day and transformed into a sample using a Marshall Hammer and 75 numbers of blows on either side of the metallic cylindrical mould. The specimen is next subjected to a Marshall Stability Test in accordance with ASTM D 1559-76. Following that, the Marshall load and flow values are noted. Then the following formulae are used to calculate the bulk volume, bulk specific gravity, percent air voids, percent VMA, and percent VFB. Thereafter graphs are generated based on the test findings.

- Marshall Stability Load, (KN), is calculated as follows: applied load in division * correction factor * proving ring factor.
- (Mass of Saturated Surface Dry Specimen in Air) = Bulk Volume (cc) - (Mass of Specimen in water)
- Mass of Specimen in Air = Bulk Specific Gravity (Gmb) (gm/cc) (Bulk Volume)
- (((Max SG of loose Mixture)-Bulk SG Specimen)) / (Max SG of Loose Mixture) * 100 = % Air Voids
- ((Bulk SG of Specimen * Percentage of Aggregates)) / 100 is the percentage of voids in a mineral aggregate (Bulk SG of Aggregate)
- % Void Filled with Bitumen = 100 * ((% Voids in Mineral Aggregate-% Air Voids)) / (% Voids in Mineral Aggregate)

3.3.2 Adherence Test

- Getting ready the sample
- Analyzing the sample's adhesiveness

3.3.2.1 Sample preparation

A 75-mm sample of compacted HMA was put on top of 500 grammes of loose asphalt mixes, which were then crushed with 10 blows of a conventional Marshall hammer.

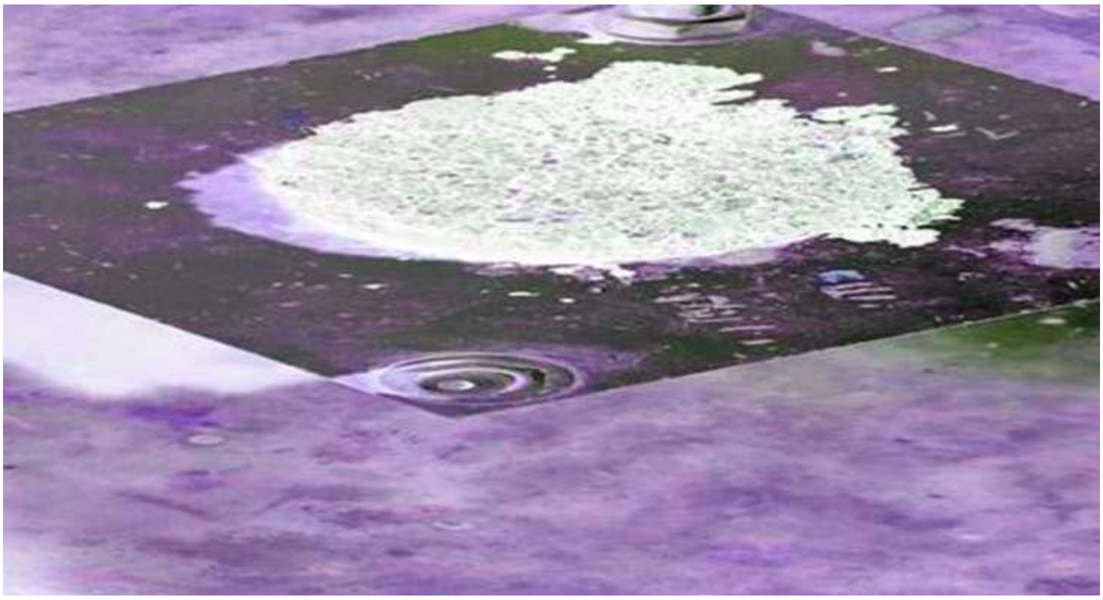

Figure 1: Moulid Ready for Adhesion Test

3.3.2.2 Measuring the sample's adhesiveness

The sample was inverted after the compressed sample was extruded. The amount of time it took for the specimen to detach from the substrate asphalt served as a gauge for the mixture's adherence. The initial batch of materials and the oven-aged (608C for 4 h) group were both evaluated. The experiment was carried out at room temperature (258C).

The cohesion or bonding within the materials is measured by the cohesion test, commonly known as the rolling sieve test. The Marshall mould,

3.3.3 Cohesion Test

- creation of the moulid
- measurement of the sample's cohesion

3.3.3.1 Sample Preparation

sealed loose cold mixtures, and a refrigerator set to 48C were all left there for 12 hours. The mould was then filled with a thousand grammes of cold mix, side with a Marshall hammer. The extruded sample was put through a full height sieve with 25.4 mm holes and a 30.5 cm diameter.

3.3.3.2 measurement of the sample's cohesion

The sieve was covered, and then it was roughly rolled back and forth on its side. The material kept and it was crushed five times on each on the sieve was then weighted to determine the amount of material lost. As a gauge of the mixture's cohesiveness, the proportion of elements that were kept on the sieve was computed. A greater percentage denotes a more cohesive substance.

Figure 2: Roll-through test

3.3.4. Test of indirect tensile strengthening

A cold mix asphalt mixture's moisture susceptibility is evaluated using the tensile strength ratio. An indirect tensile strength test was performed on the Marshall specimen in order to determine the tensile strength ratio in line with MORTH (table 500-13) and AASHTO T283.

The Marshall mix design is the same as the indirect tensile strength test's mix design. For each%, eight moulds are made. Four of the moulds are stored in conditioned conditions, while the other four are not. The lack of moisture The first batch of compacted samples had their tensile strength evaluated in an environmental room at 25 for two hours. The second batch of compressed samples was treated in a 25 degree Celsius water bath for two hours after spending 24 hours in a 60 degree Celsius water bath. At a displacement velocity of 50 mm/min and a temperature of 25, the indirect tensile strength of the dry and wet specimens was measured. Next, using the following equation, the tensile strength ratio is calculated.

$$\text{Indirect TSR} = \frac{\text{Average Indirect Tensile Strength Values of Conditioned Spec}}{\text{Average Indirect Tensile Strength Values of Unconditioned Spe}} \times 100$$

$$\text{ITS of Specimen} = (2000 * \mathrm{P})/(\pi * \mathrm{D} * \mathrm{h})$$

Where, P = Applied Load @ Failure, (KN)

D = Diameter of Specimen, (CM)

t = Height of the Specimen, (CM)

1 Division = 61.53 Newton’s /6.27 Kilograms

Figure 3: Mold was saved for testing

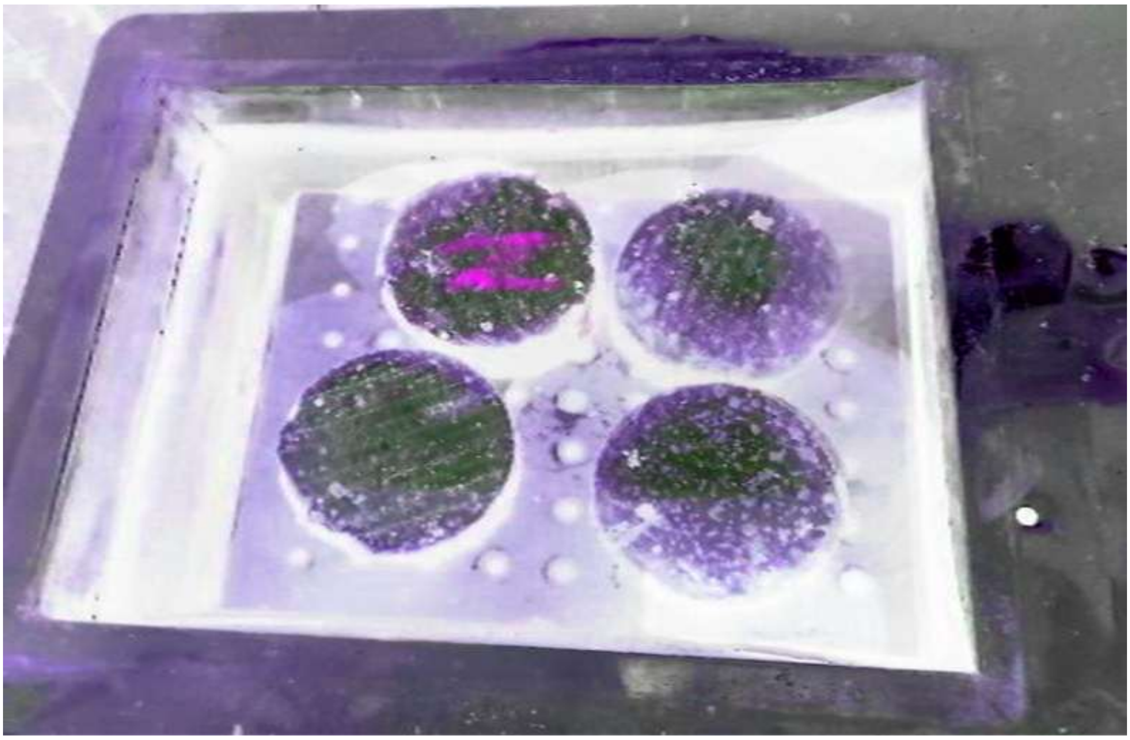

Figure 4: Molds preserved in a bath of water

4. Results and Discussion

Table 4: Findings from the Marshall Stability test

Asphalt Content (%)		
Description	**4.5**	**5**
Thickness (mm)	100.5	100.5

Height (mm)	80.50	80.50
Volume (cm^3)	628.00	635.08
Weight in air (g)	1087	1147.5
Weight in water (g)	612.00	644
Dial Reading	113.00	151.50
Flow (mm)	7.25	6.30
Stability Value (kN)	6.20	8.32
Bulk density (kg/m^3)	2288.42	2279.04
Theoretical density (kg/m^3)	2437.98	2421.90
Air voids (%)	6.13	5.9
Volume of Asphalt (%)	16.798	17.633
Void Mineral Aggregates (VMA) (%)	16.798	17.633
Void Filled with Asphalt (VFA) (%)	63.479	66.538

The table presents findings achieved in the marshal stability test for the Aggregates with cutback was tested for 4.5% and 5% binder content. To meet the minimum criteria for road pavement, the Marshall Stability value must be more than 8.0 kN, as specified by ASTM D6927-06. The maximum flow value is 0.2% by weight of bitumen, which is 12mm, therefore the value of 4.5% is 7.25 mm and 5% is 6.30 mm. Hence, 5% achieved the minimal criterion and it is considered as the optimal binder content for the test. The stability at 4.5% is therefore 6.20 kN and 5% is 8.32 kN.

4.1.1 Marshal Estates

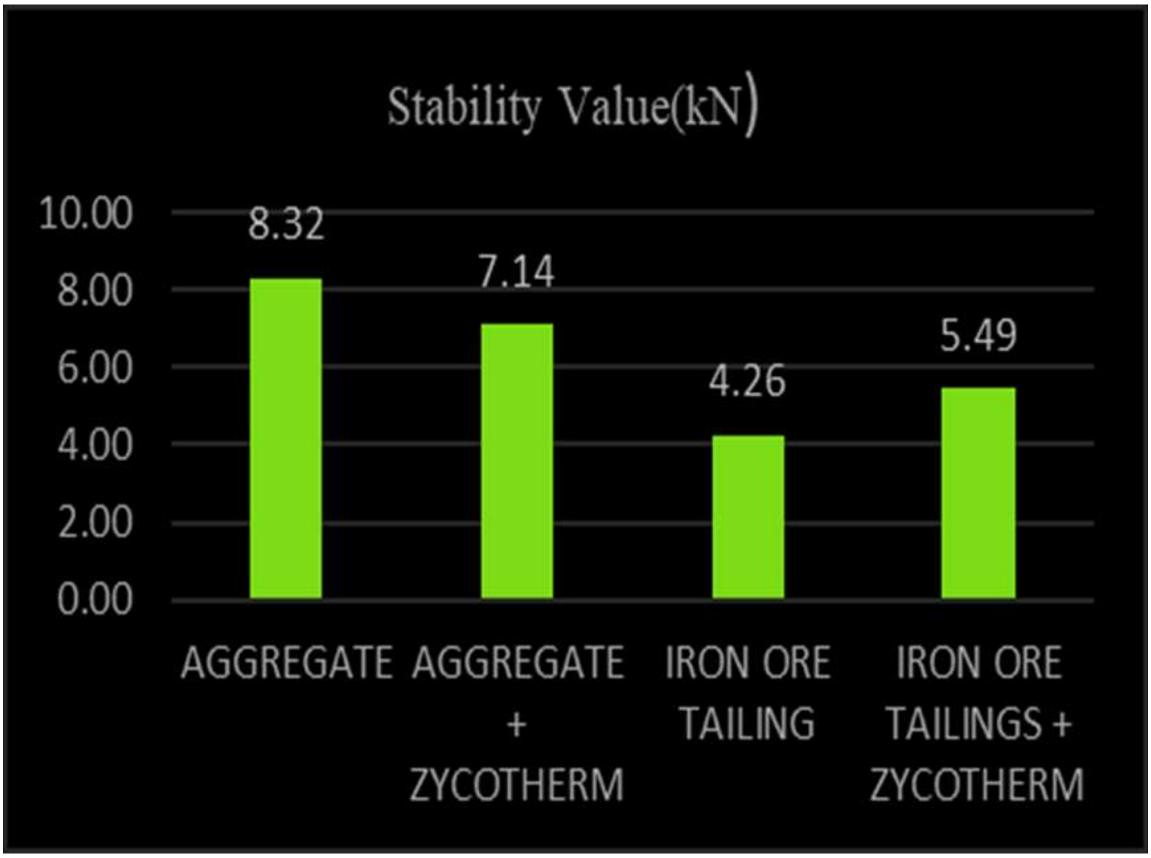

Figure 5: Stability value comparison between various samples

The graph shows the Marshall Stability values of iron ore tailing, aggregate, aggregate with zycotherm, and aggregate. Iron ore tailing sample stability is 4.26 kN, iron ore tailing with Zycotherm sample stability is 5.49 kN, aggregate sample stability is 8.32 kN, aggregate with Zycotherm sample stability is 7.14 k N.

4.1.2 The proportion of air voids

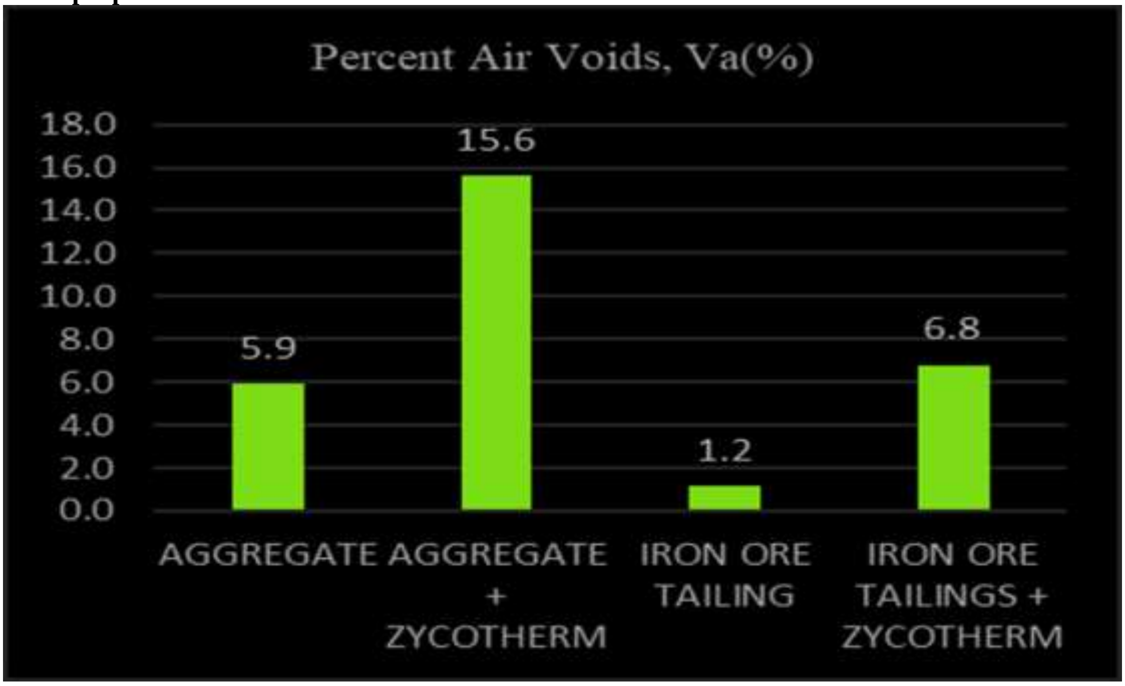

Figure 6: Comparison of air void percentages across several samples

The proportion of aggregate air spaces, Aggregate with Zycotherm, Iron ore tailing and Zycotherm-treated iron ore tailing sample. The whole sample's percentage of air voids is 5.9%. Iron ore tailing sample is 1.2%, aggregate with Zycotherm is 15.6%, and iron ore tailing sample with Zycotherm treatment is 6.8%.

4.1.3 Asphalt voids

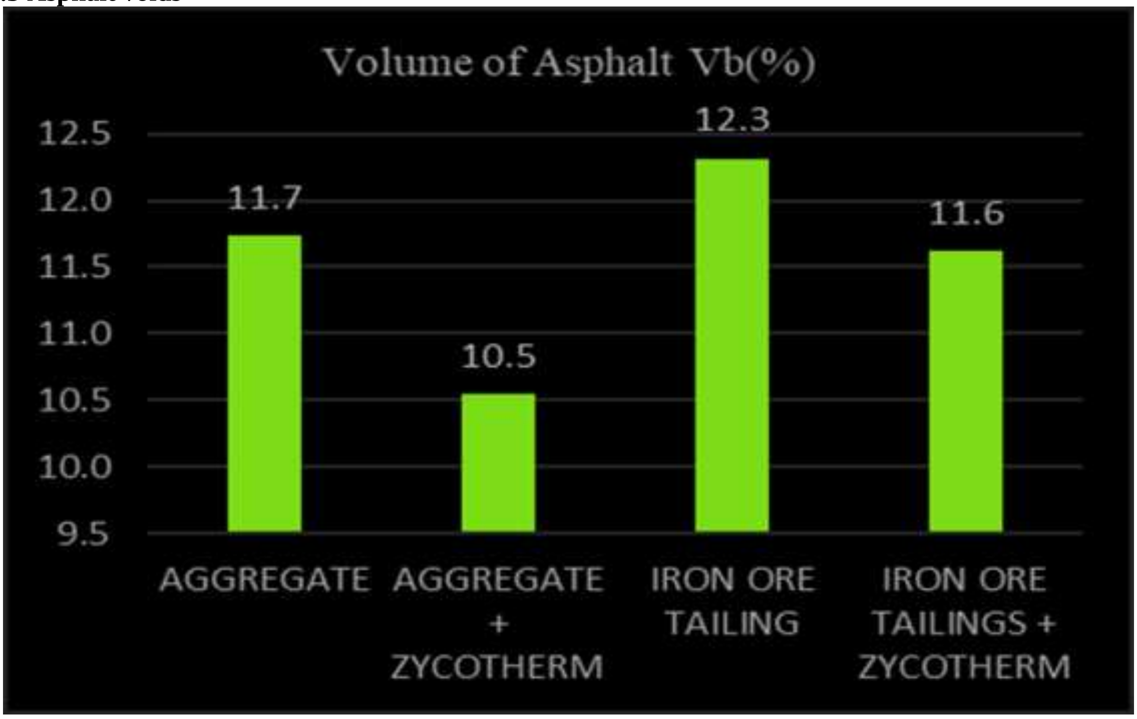

Figure 7: Comparison of the asphalt voids in various samples

The presence of asphalt voids in aggregate, aggregate treated with zycotherm, iron ore tailing, and a sample of iron ore tailing treated with zycotherm. The whole sample's percentage of air voids is 11.7%. Iron ore tailing sample is 12.3%, aggregate with Zycotherm is 10.5%, and iron ore tailing sample treated with Zycotherm is 11.6%.

4.1.4 Mineral Aggregate Porosity (VMA):

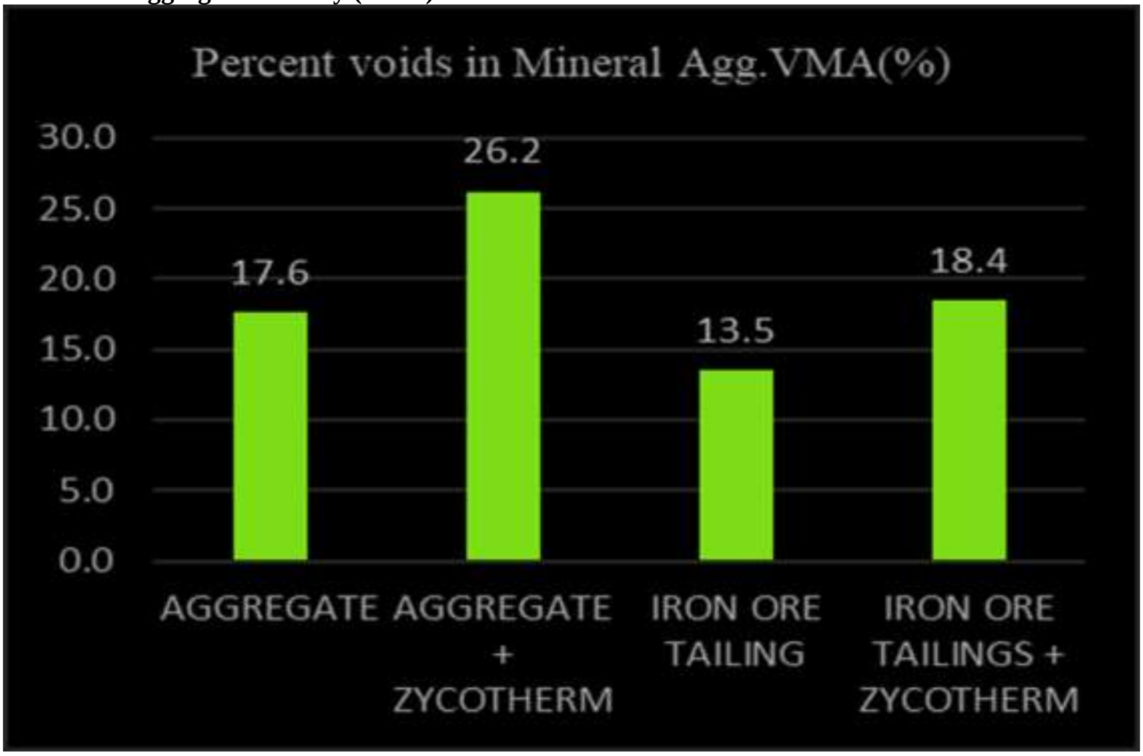

Figure 8: Comparison of the Voids in Different Samples of Mineral Aggregate

The Aggregate's Voids Minerals found in aggregate, aggregate treated with zycotherm, iron ore tailing, and iron ore tailing that has undergone zycotherm treatment. The aggregate sample's Voids in Mineral Aggregate value is 17.6%. Iron ore tailing sample is 13.5%, aggregate with Zycotherm is 26.2%, and iron ore tailing sample treated with Zycotherm is 18.4%.

4.1.5 Voids in Asphalt Filled (VFA):

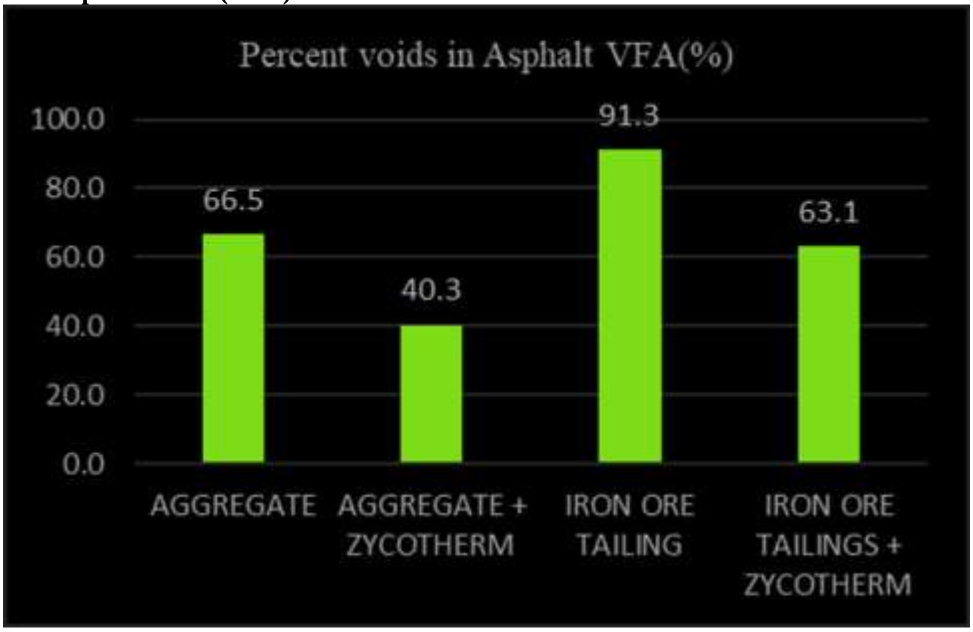

Figure 9: Comparison of the voids filled in several samples of asphalt

The holes filled with asphalt found in aggregate, aggregate treated with zycotherm, iron ore tailing, and iron ore tailing that has undergone zycotherm treatment. The aggregate sample's result for voids filled in asphalt is 66.5%. Aggregate treated with Zycotherm is 63.1%, iron ore tailing sample treated with Zycotherm is 91.3% of the total.

4.1.6 Volametric Characteristics

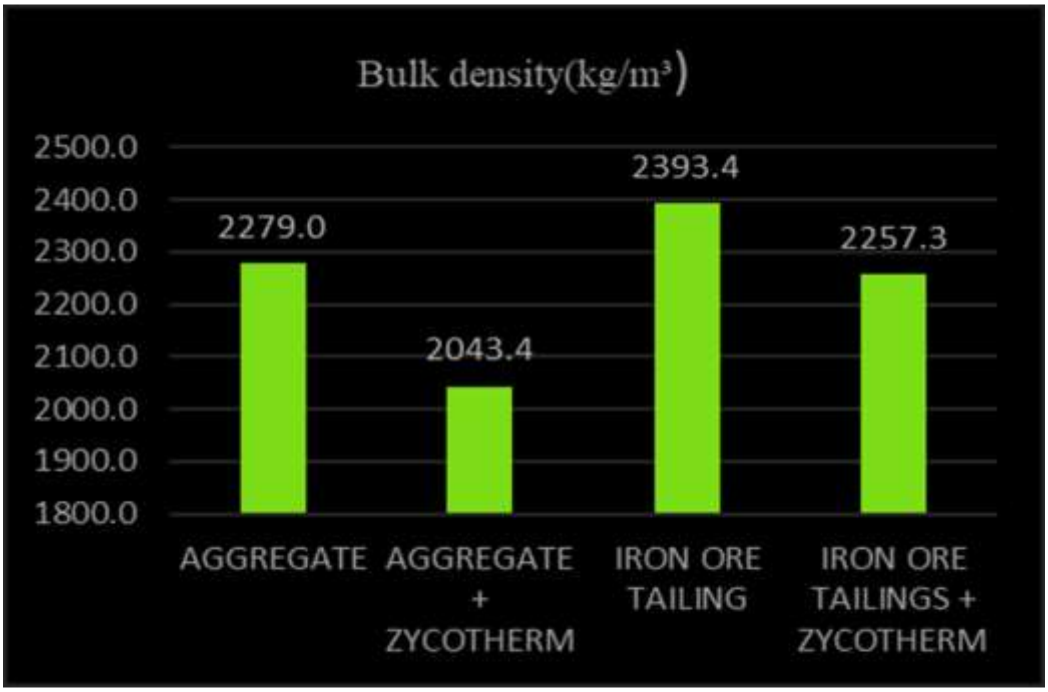

Figure 10: Bulk densities of several samples are compared

For aggregate, aggregate treated with zycotherm, iron ore tailing, and iron ore tailing treated with zycotherm, the bar graph shows volumetric parameters such as bulk density. 2043.4 kg/m3 is the bulk density of aggregate, 2257.3 kg/m3 is the weight of aggregate treated with Zycotherm, and 2393.4 kg/m3 is the weight of iron ore tailings.

4.1.7 Density Theoretically

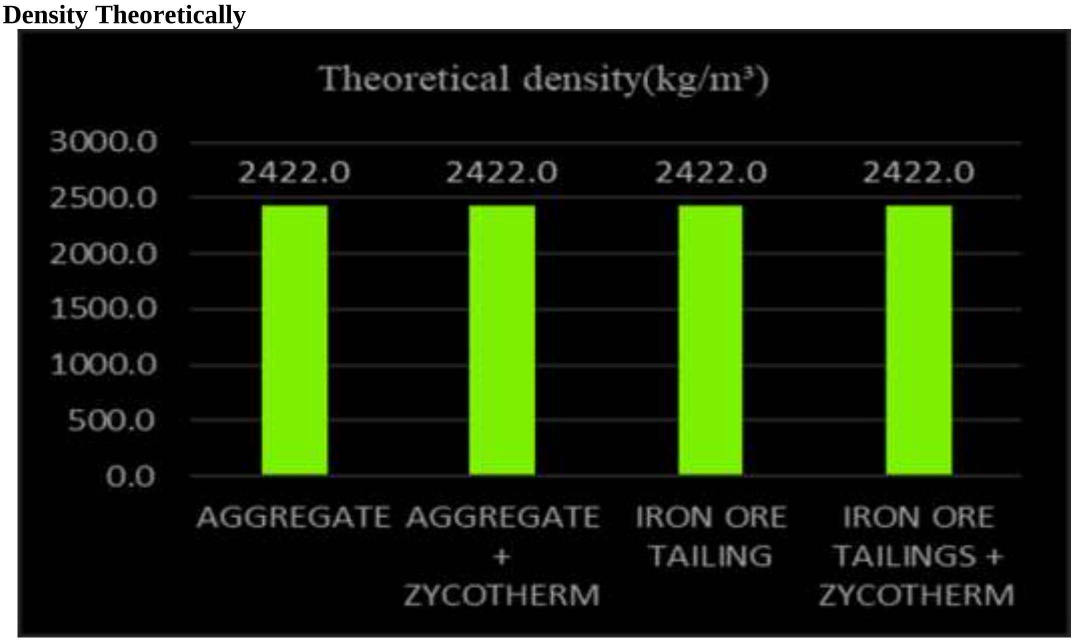

Figure 11: Analysis of the theoretical densities of various samples

The bar chart displays volumetric characteristics such the theoretical density for aggregate, aggregate treated with zycotherm, iron ore tailing, and iron ore tailing treated with zycotherm. Aggregate has a bulk density of 2422 kg/m3, as do aggregates treated with zycotherm, iron ore tailings, and aggregate treated with zycotherm.

4.2 Adhesion

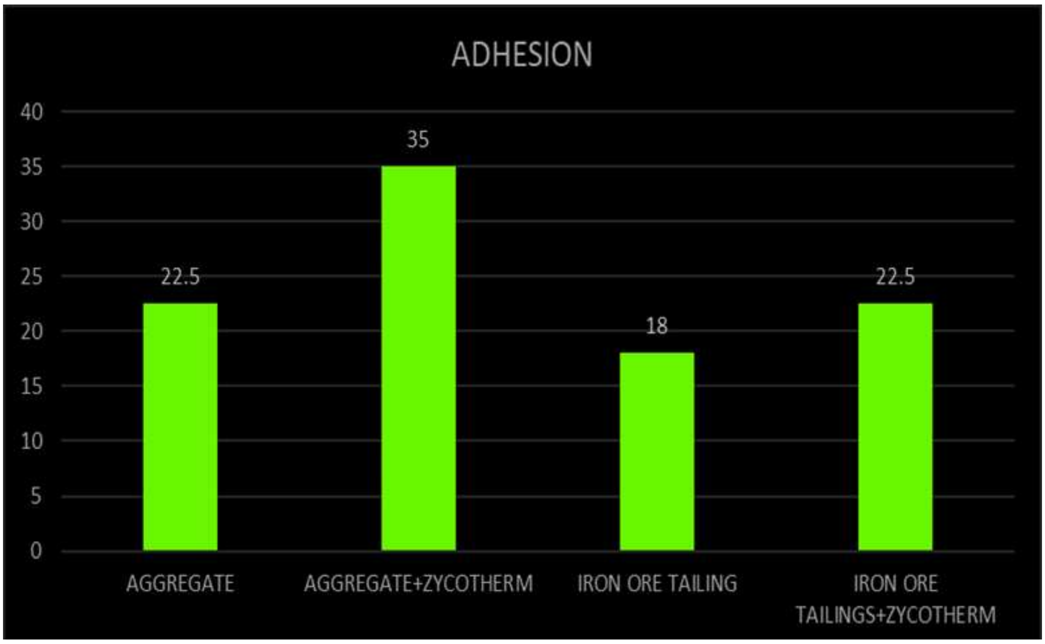

Figure 12 (a): Comparing the results of adhesion

The bar chart displays the adhesive properties of aggregate, aggregate treated with zycotherm, iron ore tailing, and iron ore tailing that has undergone zycotherm treatment. The Adhesiveness of Aggregate is 22.5 seconds, Aggregate with Zycotherm is 35 seconds, Iron ore tailings is 18 seconds, Zycotherm-treated iron ore tailing is 22.5 seconds.

4.3 Cohesion

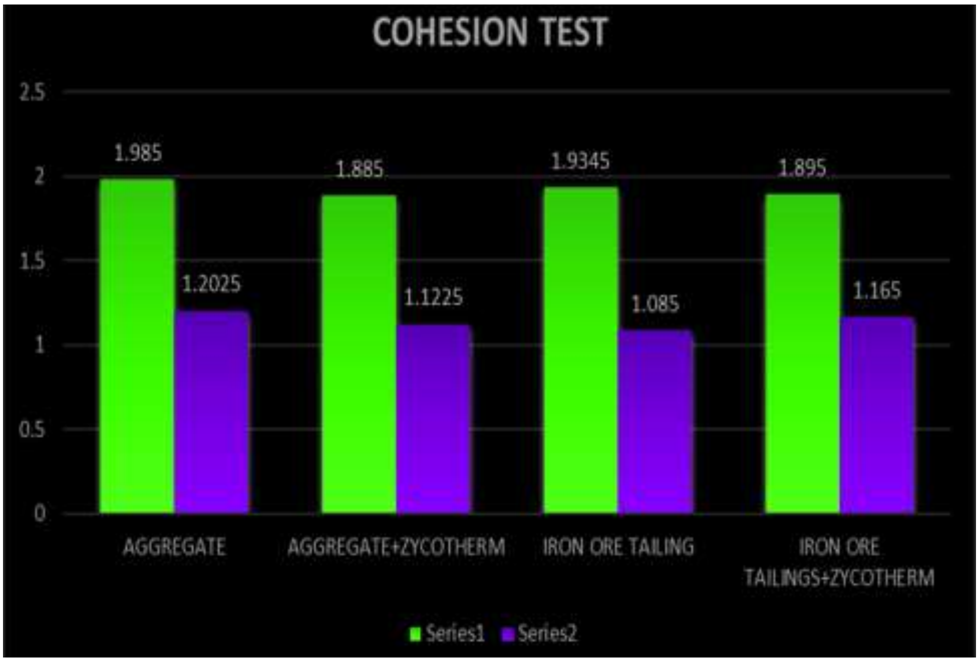

Figure 12 (b): Results of Cohesion Comparison

The bar chart displays the cohesiveness characteristics of the following materials: aggregate, aggregate treated with zycotherm, iron ore tailing, and iron ore tailing treated with zycotherm. Iron ore tailings weigh 1.9345 kg, aggregate weighs 1.985 kg, aggregate with zycotherm weighs 1.885 kg, and aggregate without zycotherm weighs 1.895 kg. Iron ore tailings weigh 1.08 kg, aggregate with Zycotherm is 1.122 kg, aggregate with rolling retains 1.202 kg, and aggregate with Zycotherm is 1.165 kg.

4.4 Test of indirect tensile strength

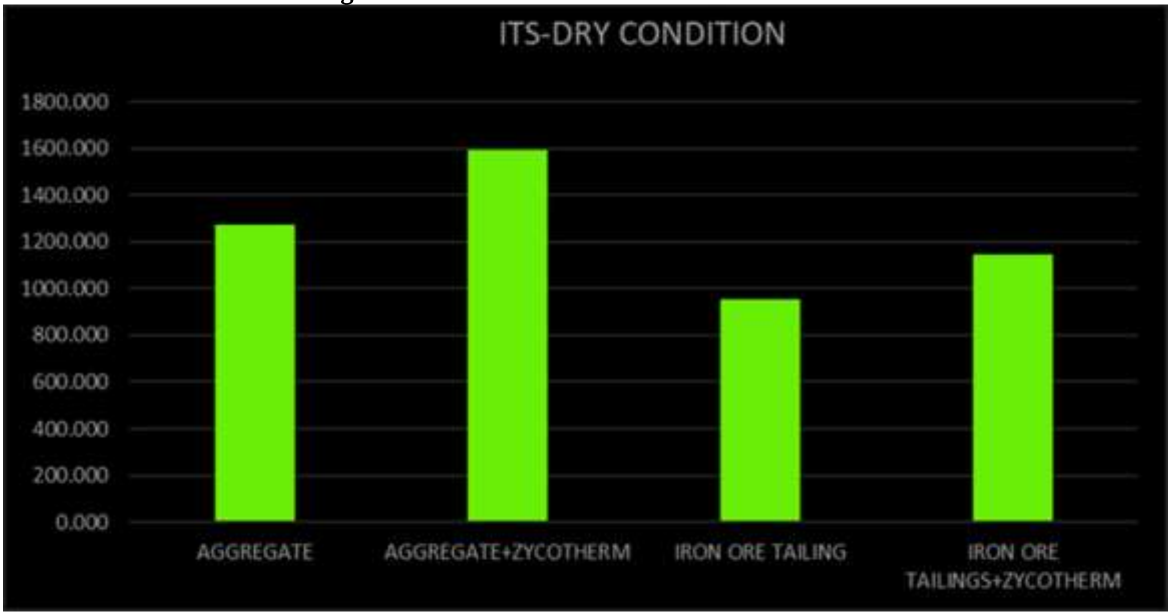

Figure 13: Comparison of Dry Condition Indirect Tensile Strength

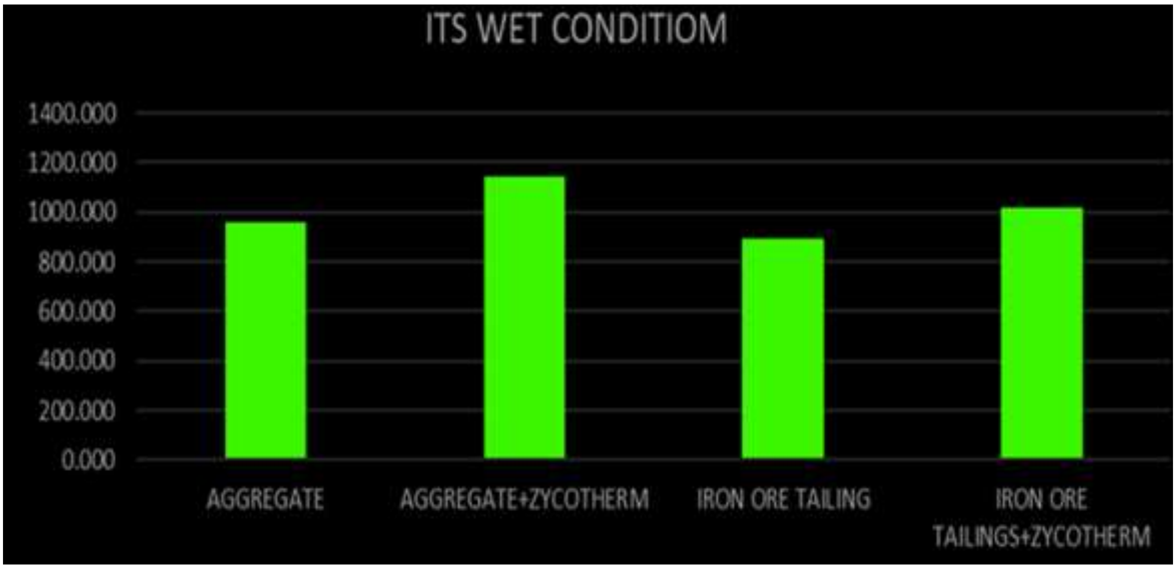

Figure 14: Comparing Indirect Tensile Strength in a Dry Environment

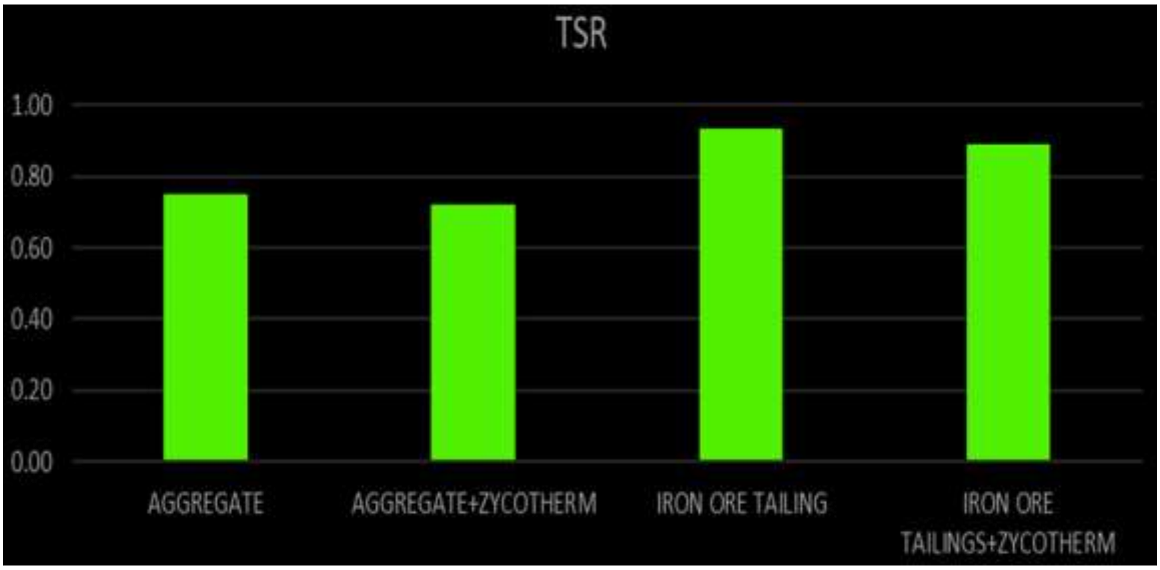

Figure 15: TSR comparison

The tensile strength ratio may be used to calculate the moisture susceptibility. TSR was found to be inadequate while evaluating moisture resistance. It is advised to test both TSR and wet ITS strength simultaneously in order to assess the moisture damage resistance of asphalt mixes. The barchart displays the TSR Value for the aggregate sample, aggregate treated with zycotherm, iron ore tailing, and iron ore tailing after zycotherm treatment. TSR for aggregate is 0.75; aggregate treated with zycotherm is 0.72; iron ore tailing is 0.93; and iron ore tailing treated with zycotherm is 0.89.

5. Conclusions

The use of Iron Ore Tailing as a substitute for traditional aggregate in asphalt mixes was the main focus of the current investigation. On the basis of the results of the experimental testing, the following conclusions are made:

- We looked at the possibility of substituting iron ore tailings (IOTs) for conventional aggregates in pothole filling mixes. It was found that by doing this, the amount of waste that could be used up would be greatly increased. You can reduce the expense of patching potholes by 20 to 30 percent.
- IOTs contain more moisture than aggregates, therefore adding them makes the mixture less workable. The cost strength increase also increases by 20 to 30% with the inclusion of IOTs.
- The sample's composition was 70% bitumen and 30% kerosene. The Marshall Stability test was run on each of them, and it was found that we had to use around 5% of the cutback bitumen, or 60g, in the aggregate or iron ore tailings total quantity, in order to acquire the required amount of flow value and stability (i.e., 1200g).
- At a cutback content of 5%, aggregates and iron ore tailings provided results that were similar in a cohesion test. Nevertheless, the cohesiveness value improved when zycothetrm was added.
- An adhesion test was performed on samples of aggregate, aggregate treated with Zycotherm, iron ore tailings, and iron ore tailings treated with Zycotherm. It was established that utilising the zycotherm, aggregate and iron ore tailings needed 22.5 seconds.
- Loaded wheel tests were done on samples of aggregate, aggregate treated with zycotherm, iron ore tailings, and iron ore tailings treated with zycotherm in both dry and wet circumstances. The iron ore tailings will be more temperature and load resistant than aggregates.

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