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PROPERTY ANALYSIS OF INDUCTION FURNACE STEEL SLAG FOR USE IN FLEXIBLE PAVEMENT

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ABSTRACT

Byproduct obtained from induction furnace steel industry costs high for its disposal. Despite of using for some constructions and land filling a large number of steel slag(IF) is disposed in stockpiles to date. Recycling of this byproduct would be proper option for saving natural resources, land and environmental balance. Focusing on that, this extraction and analysis is carried out to observe compatibility of steel slag(IF) for use in flexible pavement. Different percentages of slag(25%,50%,75%) are taken in mixed with natural stone (75%,50%,25% respectively) including a 100% stone and a 100% slag set for extraction of property curves for medium traffic by Marshall Mix Design. A particular gradation of aggregate, bitumen grade and same stone are used for all sets to get an identical and comparable result. AIV and ACV are obtained to identify aggregate property of slag to be used in flexible pavement. Cost analysis is done to compare with conventional approach. Property curves of slag mixed are found rebounded and different in shape from 100% stone for some cases. Curve analysis shows a higher optimum bitumen content for slag than full stone set as expected. Optimum bitumen content reaches up to 31% higher than 100% stone set for 75% slag set. 100% slag set shouldn't be considered in surface course as it doesn't fulfill all prescribed property values. For stability we observe 60%,33%,27%,16% higher values for 100%,75%,50%,25% slag sets respectively than that of in full stone set. 75% and 100% slag sets show anomalous result for ACV, AIV and so, shouldn't be accepted to use. 50% and 25% slag sets satisfy the aggregate requirements experimented limitedly. Total cost of materials in surface course can be reduced using slag as slag(IF) doesn't create significant monetary value yet. Higher cost for bitumen can be compensated by cheaper slag. As pothole is one of the major problems in roadway, steel slag can be an option for higher stability. In the road near to the steel industries it can be recommended highly to reduce transportation cost as well as proper management of slag.

Keywords: *Steel slag(IF), Flexible Pavement , Marshall Mix Design, Curve Analysis, Cost.*

1. INTRODUCTION

Large quantities of natural materials (stone) are traditionally used in road construction(Barišić et al.,2010). This leads to gradual depletion of natural resources which are non-renewable and leads to environmental destruction and distortion of natural balance(Barišić et al.,2010). So, finding alternatives of natural aggregates has become necessary. The generation, handling, and safe disposal of solid wastes has become a major concern. While the volume of wastes continues to grow, approval of facilities for waste processing and proper disposal is becoming more difficult to obtain. Reusing such materials reduces disposal volumes and costs, conserves natural resources, and may even generate revenue.

Steel slag is a waste material generated as a by-product during the manufacturing of steel from steel industries (Sinha et al.,2013). It is used just for some construction and landfilling but huge amount of steel slag is disposed in stockpiles to date(Hainin et al.,2015). The utilization of waste materials such as steel slags in road construction is gradually getting significance due to difficulty in waste disposal, environmental problems and gradual depletion of natural resources. Steel slag consists principally of a fused mixture of oxides of calcium, silica, iron, alumina and magnesium.(YI,2008) . The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling(YI,2008). It has some characteristics which almost similar to conventional aggregates. Steel slags are angular in shape and have rough surface texture which provides better interlocking of particles(Hainin et al.,2015). Its sharp concern and rough pitted surface grip the ties firmly and prevent shifting of the track on curves. It provides better drainage because it's high percentage of void space, It contains no organic substance and is an exceptionally clean ballasting material that will not support the growth unwanted vegetation. It also has strong affinity to binder. Steel-slag aggregates have been reported to retain heat considerably longer than natural aggregates(Hainin et al.,2014). Steel slags are hydrophobic (strong affinity with binder), basic or alkaline in nature having pH value of around 8-10(Hainin et al.,2014). Whereas the bitumen binder normally acidic, having a naturel chemical affinity with steel slags and the pH value of bitumen binder is less than 7. This property of steel slag provides a good adhesion and helps to resist against the stripping.

Steel slag is a waste material which can be used as a road construction material and It can reduce depletion of natural aggregate and reduce the cost of road construction. Also it will reduce waste disposal cost and large area of land will not be sacrificed for the disposal of this useful material.

2. METHODOLOGY

Steel slag aggregates were collected from steel manufacturing company. Aggregates were sieved properly for each test. Stones were also collected and properly sieved. Both steel slag and stone were properly mixed to create the mixed batches.60/70 grade bitumen with specific gravity of 1.019 was collected from the laboratory. Aggregate tests were done to determine the desired parameters for each sample. The values of the experiment for each sample were recorded and a comparative study was done to determine suitable and cost-efficient mixture.

2.1. Sieving and Mixing of Aggregates

Sieve sizes used for particle size distribution of aggregate are: 25 mm,19.5mm, 12.5mm ,9.5mm, 4.75mm, 2.36mm, 0.6mm, 0.075mm., 14.0mm BS test sieve and 10.0mm BS test sieve. Aggregates are properly sieved and each size of particles are stored separately.
After sieving both steel slag and stone aggregates ,proper mixture of these aggregates are prepared.
Sieve analysis for different batch are shown in **Table 1.** Mixing is done on weight basis.
5 types of sample are taken:

1) 100% SG (100% steel slag)
2) 75% SG (75% steel slag + 25% stone)
3) 50% SG(50%steel slag + 50% stone)
4) 25% SG(25%steel slag + 75% stone)

5)0% SG(100% stone)

Table 1: Sieve analysis for different combinations

Sieve Size [mm]	**100% Slag**	**75%Slag+25%Stone**			**50%Slag+50%Stone**			**25%Slag+75%Stone**			**100%Stone**
	Material Retained (gm)	Materials Retained(gm)			Materials Retained(gm)			Materials Retained(gm)			Materials Retained(gm)
		Slag	Stone	Sum	Slag	Stone	Sum	Slag	Stone	Sum	
25	29	21.75	7.25	29	14.5	14.5	29	7.25	21.75	29	29
19.5	87	65.25	21.75	87	43.5	43.5	87	21.75	65.25	87	87
12.5	231	173.25	57.75	231	115.5	115.5	231	57.75	173.25	231	231
9.5	81	60.75	20.25	81	40.5	40.5	81	20.25	60.75	81	81
4.75	225	168.75	56.25	225	112.5	112.5	225	56.25	168.75	225	225
2.36	150	112.5	37.5	150	75	75	150	37.5	112.5	150	150
0.6	139	104.25	34.75	139	69.5	69.5	139	34.75	104.25	139	139
0.075	133	99.75	33.25	133	66.5	66.5	133	33.25	99.75	133	133
Pan	80	60	20	80	40	40	80	20	60	80	80
Total	1155	1155			1155			1155			1155

2.2. Testing of Aggregates

The following experiments were performed:

- Determination of Aggregate Impact Value (BS 812-112)
- Determination of Aggregate Crushing Value (BS 812-110)
- Determination of maximum specific gravity of each mixture (ASTM D 2041-91)
- Determination of specific gravity of Coarse aggregate (ASTM C127-88)
- Determination of specific gravity of Fine aggregate (ASTM C128-88)
- Marshall Mix Design (ASTM D 1559)

2.3. Property Curve Analysis

Property curves have been constructed after interpreting experiment data. Shape of these curve have significance to determine optimum value. All the combinations are compared with respect to different properties.

2.4. Cost Analysis

To compare which combination is more cost efficient ,cost analysis was conducted. It finds the combination that meets all the criteria and also very cost efficient. Cost analysis has been conducted based on several assumptions.

- Length of the road was assumed to be 1 km, width=7.4m and thickness of wearing surface = 0.2m. So, volume of the road was determined.
- Cost of materials for 1 meter cube volume was taken on the basis present market value
- Total cost for each combination was determined using the cost rates
- Comparison was made between the combination on the basis of cost analysis

3. ILLUSTRATIONS

3.1. Figures and Graphs

3.1.1. Comparison of bitumen content

Bitumen contents at optimum level have been observed. Different percentages have been found for different combinations. Amount of bitumen content increases with increase in slag percentage as more pore requires more bitumen (shown in **Figure 1**). Least amount of bitumen requires for fresh aggregate and increases up to 31.25% for 75% slag + 25% stone combination as shown in **Figure 2**.

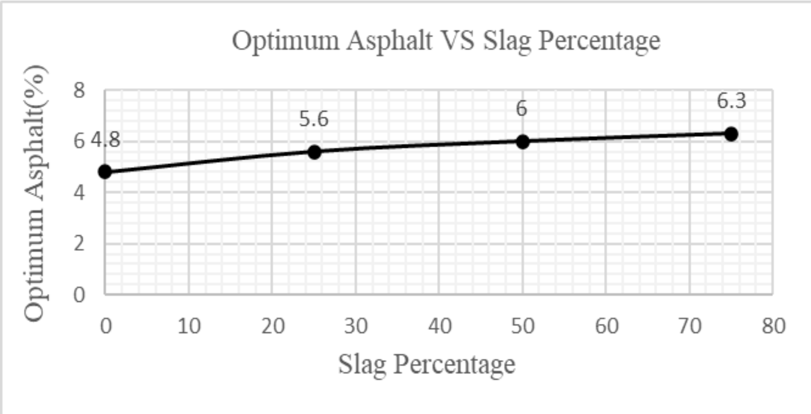

Figure 1: Optimum bitumen contents for different slag percentages

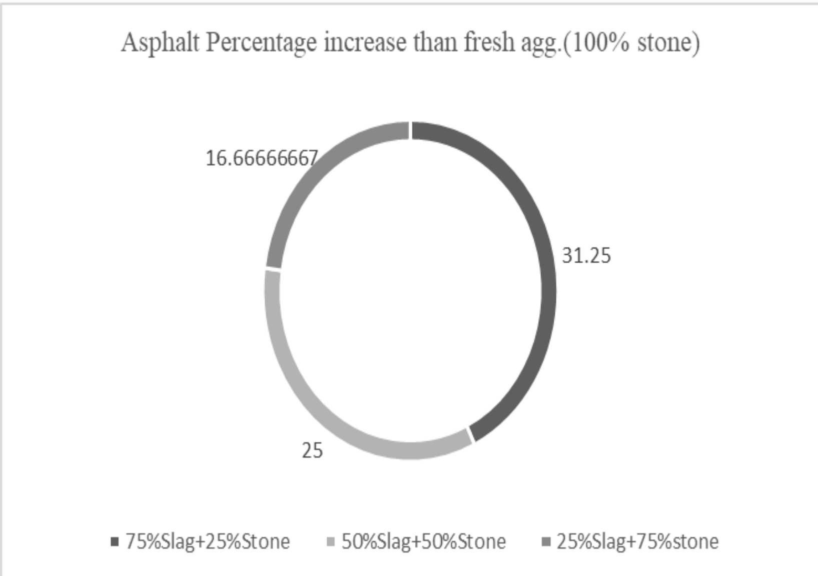

Figure 2: Asphalt percentage increase than fresh aggregate (100% stone)

3.1.2. Comparison of stability value

Stability Values at optimum level have been observed. Different values have been found for different combinations. Slag imparts more stability than stone. More the percentage of slag more the stability as shown in **Figure 3**. As pothole is a common problem for flexible pavement, slag can be a solution. Stability increases up to 60.2% than conventional stone aggregate for 100% slag combination (shown in Figure 4).

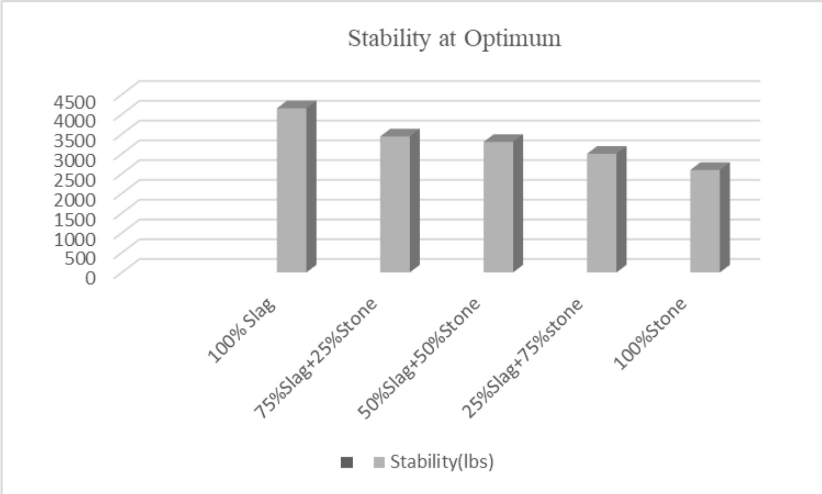

Figure 3: Stability at optimum for different combinations

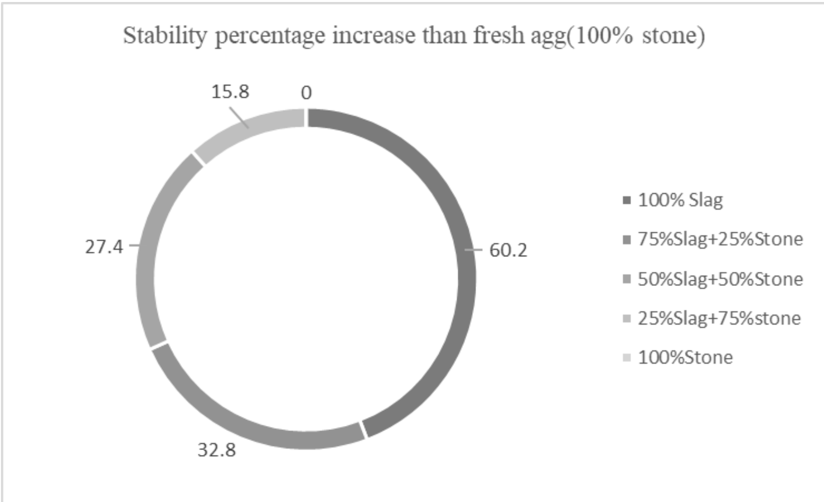

Figure 4: Stability percentage increase than fresh aggregate

3.1.3. Comparison of AIV and ACV

AIV and ACV at optimum level have been observed. Different values have been found for different combinations. AIV increases with increase in slag contents as shown in Figure 5. 75%,100% slag combinations show AIV greater than 30. So, considered as anomalous and shouldn't be used in pavement. ACV increases with increase in slag contents as shown in Figure 6. 75%,100% slag combinations show ACV greater than 30. So, considered as anomalous in terms of ACV too.

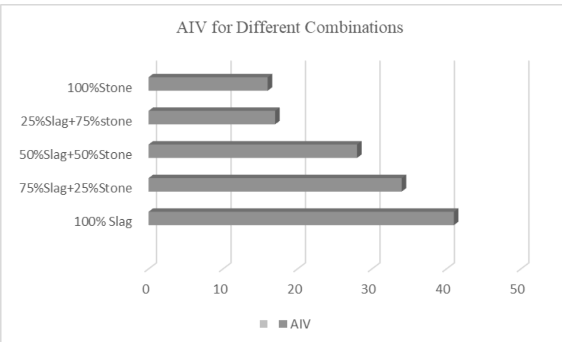

Figure 5: AIV for Different Combinations

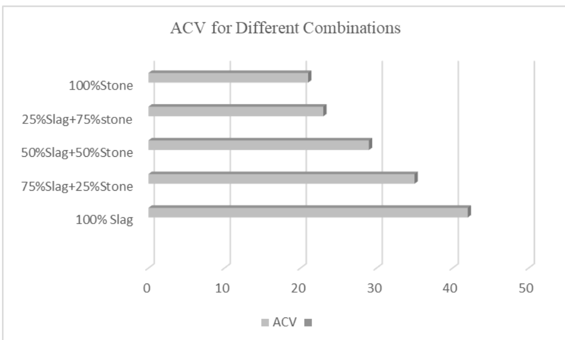

Figure 6: ACV for Different Combinations

3.1.4. Cost Analysis

Cost analysis has been conducted based on several assumptions. A roadway has been imagined of Length = 1km = 1000 m; Width = 2 lane @ 3.7m = 7.4 m; Surface Course thickness = 8" = 0.2 m Volume of Surface Course = 1480 m3 = 52265.71 ft3

Rates;

- ✓ Fresh Aggregate (Stone Chips) = 7000 BDT per 1m3 (includes materials cost, transportation, crushing cost) = 198.3 BDT per 1 cft.
- ✓ Steel Slag aggregates = 880 BDT per 1m3 (No materials cost; includes crushing and transportation cost) = 24.9 BDT per 1cft.
- ✓ Bitumen (60/70 grade) = 59,330 BDT per tonne = 26.9 BDT per lb.

Aggregate cost decreases with the increase in slag as induction furnace steel slag doesn't create significant monetary value yet. Substitution of stone by slag can reduce aggregate cost up to 66% as shown in Figure 7.

Figure 7: Cost of aggregates for the assumed surface course

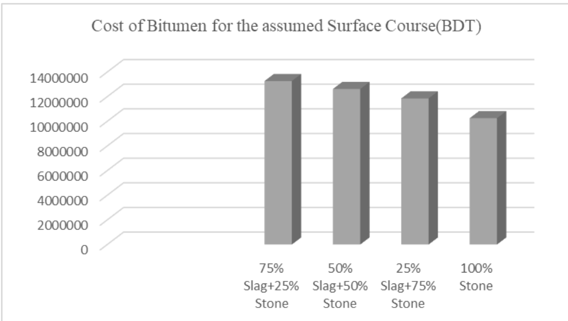

Figure 8: Cost of bitumen for the assumed surface course

Bitumen costs higher for higher slag percentage as shown in **Figure 8**. But higher bitumen cost can be compensated by low value slag aggregate. Total materials cost of the assumed surface course can be reduced up to 17% by use of slag (shown in **Figure 9**) until it creates significant monetary value.

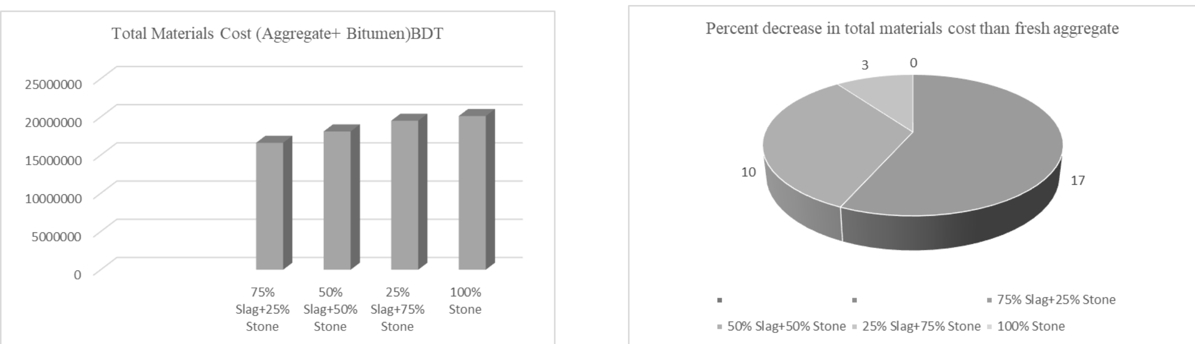

Figure 9: Total materials (Aggregate + Bitumen) cost for the assumed surface course

3.1.5. Table

Different Marshal property values at optimum level for different combinations are shown in Table 2.

Table 2: Different property values at optimum for different combinations

Combination	Optimum Asphalt Content,%	Percent Air Void at Optimum	Density at Optimum (lb/cft)	Flow at Minimum (1/100 in)	Stability at Optimum (lbs)	VFA at Optimum %	VMA at Optimum %
100% Slag	5.3	4	150.95	14.2	4150	68	12.9
75%Slag+25%Stone	6.3	4	149.8	17	3440	73.5	14.75
50%Slag+50%Stone	6	4	149.6	10.7	3300	72	15.13
25%Slag+75%Stone	5.6	4	150.6	14.6	3000	70	14.7
100%Stone	4.8	3.3	151.9	10.9	2590	75	13.7

4. CONCLUSIONS

Experiment based data of Marshall Mix Design (for medium traffic), ACV, AIV have been analysed including cost comparison. Comparative study has been conducted with those analysed data. Slag imparts better stability but consumes more bitumen than conventional stone aggregate. Higher cost for bitumen can be compensated by low value of slag aggregate as induction furnace steel slag doesn't create any monetary value yet. But 100% slag and 75% slag + 25% stone combinations shouldn't be used in flexible pavement as aggregate because of being anomalous in ACV and AIV tests. Conventional stone aggregate can be substituted up to 50% with induction furnace steel slag for being beneficiary with higher stability and cost efficiency (a summary shown in **Table 3**). For 50% slag + 50% stone combination, stability increases 27.4% and cost decreases 10% than that of full (100%) stone aggregate.

Table 3: Summary of final remarks

100% Slag	✓ Better in stability ✓ Anomalous in ACV, AIV ✓ **Rejected.**
75% Slag + 25% Stone	▪ Better in stability and cost ▪ Anomalous in ACV, AIV ▪ **Rejected**
50% Slag + 50% Stone	❖ Better in stability and cost ❖ Not anomalous in ACV, AIV ❖ **Can be accepted**.
25% Slag + 75% Stone	➢ Better in stability and cost ➢ Not anomalous in ACV, AIV ➢ **Can be accepted.**

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LIMITATIONS

- ❖This research is conducted only for use in surface course not in base or subbase of pavement.
- ❖This analysis is only applicable for medium traffic not for high.
- ❖LAA (Los Angeles Abrasion test) should be conducted for each of the combinations.
- ❖The properties of slag vary from company to company.

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