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Marshal Characteristics of Hot Mix Asphalt Concrete Modified with Steel Rolling Furnace Dust (SRFD)

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ABSTRACT

The study aimed to enhance asphaltic concrete properties by utilizing Katsina Steel Rolling Furnace Dust (SRFD) waste, estimated at 15-20 kg per ton of produced steel, as an additive. SRFD was incorporated into the asphalt mix at varying concentrations (0%, 2%, 4%, 8%, and 10%) by volume of binder. Optimal bitumen content was established at 5.4%, meeting the General Specification of Nigeria Roads and Bridges, 2016. Properties like stability, flow, VMA, VFB, and Pa fell within the specified range. The modified asphalt, containing SRFD, exhibited improved stability (6.61kN compared to 5.4kN in the control asphalt) and a flow of 3.9mm. This alteration led to increased bulk density, suggesting potential structural reinforcement against road pavement distress caused by traffic loads. Results from the one-way ANOVA test indicated that SRFD didn't significantly impact stability, flow, or % air voids (p-values > 0.05 and F cal. < F crit.). However, SRFD did play a significant role in unit weight, VMA, and VFB variance. Marshal Quotient values were determined for different SRFD-modified asphalt mixes, with the highest value of 2.55 indicating enhanced stability and reduced flow, potentially offering high resistance to rutting. Analysing SEM ImageJ data revealed that SRFD-modified HMA exhibited a greater spread in particle distances, with Particle Mean length and area measuring 7,825.87 micrometres and 964,775.7 sq. micrometre, respectively, and an S.D. of 2,615.615 micrometre. In contrast, the control HMA showed closer particle distance deviation, with Particle Mean length and area of 235.659 micrometre and 259.09 sq. micrometres, respectively, and an S.D. of 234.2 micrometre

Keywords: *Marshal quotient, steel rolling furnace dust, marshal properties, analysis of variance*

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INTRODUCTION

Researchers worldwide have extensively investigated the utilization of various materials and industrial by-products, such as waste plastic, lignin, high-density polyethylene, softwood bark charcoal, nano clay waste, graphene oxide, eggshell powder, and steel rolling furnace dust (SRFD), among others. Instead of disposing of these materials in landfills, there's growing interest in incorporating them as modifiers and additives in concrete and hot mix asphalt production. SRFD, a by-product of the steel hot rolling process, has a variable chemical composition based on the steel type and production process. It contains metals in the form of free oxides and composite structures with iron oxides. These components have shown potential for enhancing compressive strength, reducing water absorption, and increasing apparent density in hot mix asphalt. The production of mill scales or dust, considered waste, could reach several million tons globally. This waste stems from advancements in steel production technology over the past two decades, where methods like open hearth and basic oxygen converters have been superseded, with the newer technology accounting for about 33.4% of the world's share in 1999 (Cristiana et al., 2010). Steelmaking by-products such as mill scale and furnace dust are generated in substantial quantities worldwide, with estimates reaching nearly 5 million tons annually (Dana et al., 2017). Globally, steel rolling furnace waste contributes approximately 13.5 million tons each year. Among these by-products, mill scale has proven viable for direct recycling into ferroalloys, as well as for use in cement manufacturing, petrochemical processes, and the construction industry (Gaballah et al., 2013). Despite these potential applications, the large-scale production of steel rolling furnace dust (SRFD) poses significant environmental concerns. SRFD cannot be incinerated or composted, leaving landfilling as the only conventional disposal method. However, this approach is detrimental to soil health and poses long-term risks to the environment. These challenges have motivated the current research, which explores an alternative solution by evaluating the Marshall properties of hot mix asphalt concrete incorporating SRFD as an additive. This investigation aims to determine whether SRFD can be effectively repurposed in road construction, thereby mitigating its environmental impact.

MATERIALS AND METHODS

Materials

The materials used in this research study are bitumen (60/70 cut back), granite aggregate (coarse), Ordinary Portland cement (OPC), and Steel rolling furnace dust (SRFD). The bitumen and aggregates were obtained from Mother Cat Nigeria Limited situated at No. 15, Mother Cat Road, Off Nnamdi Azikiwe Express Way, Kaduna. The Portland cement was obtained from a cement depot in Zaria and the Steel mill scale dust from Katsina steel rolling mill, Katsina State.

Methods

The laboratory procedures that were conducted in carrying out this research work are:

Bitumen

Technological Tests

Penetration test (ASTM D5 / D5M-20, 2020)., Ductility test (ASTM D113-17, 2017). Softening point test (ASTM D36 / D36M-14, 2020). Flash and fire point (ASTM D92-18, 2018), Solubility test (ASTM D2042-15, 2015).

Physical Test

Specific gravity (ASTM D70/D70M-21, 2021))

Aggregates

Physical Test

Elongation index (ASTM D4791-19, 2019), Flakiness index (BS EN 933-3, 2012, Specific gravity (ASTM C127-15, 2015; ASTM C128-15, 2015), Sieve Analysis (ASTM C136 /C136M-19, 2019)

Mechanical Tests

Aggregate crushing value test (BS 812-110, 199), Aggregate impact value test (BS 812-112, 1990). Los Angeles abrasion test (ASTM C131/C131M-20, 2020).

Marshal Method for Control HMA

Proportioning of Aggregates

The proportioning of aggregates was done in accordance to the Federal Ministry of Works General Specification for Road and Bridges of the Federal Republic of Nigeria, 2016.

Preparation of Pure HMA (Control)

The methods used in obtaining the pure hot mix asphalt are as follows: The pure HMA (control) was prepared in accordance to ASTM Standard (ASTM D6926-20, 2020).

Laboratory Tests on the Control HMA

The laboratory tests carried out on the control HMA were.

Physical test

Bulk Specific Gravity Test (AASHTO T 166, 2016). The void analysis involves (void in the compacted mineral aggregates VMA, voids filled with bitumen VFB.

Mechanical test

Marshal Stability and Flow Tests

The stability is defined as the maximum load resistance in kN that the specimen will achieve at 60^{O}C under specified conditions. The flow is the total movement of the specimen in units of 0.01mm during the stability test as the load is increased from zero to the maximum. These were carried out in accordance to ASTM Standard (ASTM D6927-15, 2015).

Scanning Electron Microscopy (SEM)

SEM test was conducted at the department of chemical engineering of the faculty of engineering, ABU Zaria. SEM uses an electron beam to produce magnified images for the purpose of analysis. SEM analysis carried out on the control asphaltic concrete, and the SRFD modified asphalt concrete so as to check the interaction between the microstructure of the components that make up each of these mixtures.

RESULTS AND DISCUSSION

Test Results on Bitumen

The results obtained for the properties of the bitumen used are as shown in (Table 1), it can be observed that the entire test conducted falls within the specification for medium weight traffic as 60/70 penetration grade bitumen per the specification of the Federal Ministry of Power, Works, and Housing (FMPW&H, 2016). As such, the bitumen can be used for medium-weight traffic flexible pavement design. As such, the identified properties of the bitumen sample indicate that the bitumen is suitable for use as a binder in an asphalt mixture of the proposed research work.

Table 1: Test Conducted on the Bitumen.

Test Conducted	Unit	Result	Light Traffic	Medium Traffic	Heavy Traffic
Penetration	0.1mm	67.1	40/50	60/70	80/100
Softening point	ºC	51.9	52-60	48-56	42-50
Ductility @ 25ºC	cm	112.2	100 (Min)	100 min	100 min
Specific gravity	NIL	1.02	1.01-1.06	1.01-1.06	1.01-1.06
Flash-point	ºC	256	250 (Min)	232 min	250 min
Fire-point	ºC	280	NIL	NIL	NIL

Marshal test method for SRFD modified HMA

The optimum bitumen content of the control HMA is used for the modified SRFD HMA that yielded the maximum stability, maximum bulk unit weight, and the average of the limits of the percent air voids in the modifies mix at various modifier contents as illustrated in (Tables 2 & 3), it can be clearly observed that the properties of the SRFD modified HMA at 2%, 4%, 8% and 10% modifier contents, met with the prescribed specifications, but 8% and 10% modifier contents failed with respect to the Marshall Flow properties.

Analysis of Variance (ANOVA)

An analysis of variance on the SRFD modified hot mix asphalt was calculated at a significance level of 0.05 to analyze the data of the marshal stability, flow, bulk density, % Air voids, Voids in Mineral Aggregates and Voids filled with Bitumen. Judging by the P-values obtained at a significant level of 0.05, if the values obtained are greater than 0.05, it means that there is no statistically significant difference between means due to a factor. Table 4 shows results for ANOVA. From the table, the P-values obtained for stability, flow and % Air voids are 0.517292, 0.062005 and 0.229759 respectively which are all greater than 0.05 and thus implies that the SRFD additive has no significant effect on these three properties statistically. The values for bulk density, voids in mineral aggregates and voids filled with bitumen which are 0.030184, 3.48E-05 and 7.21E-11 respectively are all less than 0.05 and implies that the SRFD contents result in significant change in the properties.

Marshal Stability, and Flow and Marshal Quotient

When compared to the control sample, Table 5 shows that the asphalt mixture containing the steel rolling furnace dust additive has better stability values, suggesting that these asphalt mixtures have a high load-withstanding strength. An asphalt mixture with a high flow value will not be resistant to rutting; hence, a desirable combination should have a low flow value. For various percentages of SRFD-modified asphalts, the Marshal Quotient values were calculated. The asphalt combination has the lowest flow and the most stability, as indicated by its highest Marshal Quotient of 2.55 SRFD (Nur Mustakiza et al., 2018).

Scanning Electron Microscopy (SEM)

Using the scanning electron microscopy, the various mixtures' morphology and microstructure were examined. Three distinct blends' microstructures are displayed on (Figures 1 and 2). Plate 8 demonstrates how the bitumen binder has completely covered the particles, giving the asphaltic concrete a structure that is tightly packed. Comparing the SRFD-added mix to the control mix, Plate 9 demonstrates that there was an increase in voids and a decrease (Figures 1 and 2).

SEM Image J Analysis

Version of ImageJ software: j153-win-java8 was utilized to analyze the SEM images' thresholding, length/area, and standard deviation (S.D.) measurements. Particle mean length, area, and standard deviation on the modified HMA image were 7825.87 micrometers, 964775.7 sq. micrometers, and 2615.615 micrometers, respectively; on the control HMA image, these values were 235.659 micrometers, 259.09 sq. micrometers, and 315030.2 micrometers (Figures 3 and 4).

Particle Distance and Area Measurement

Several ImageJ functions can be used to calculate the distance between particles once they have been identified.

Table 2: Marshall test for SRFD Modified HMA

SRFD (%)	Stability (kN)	Flow (mm)	Unit weight (g/cm^3)	Pa (%)	VMA (%)	VFB (%)
0	5.52	2.41	2.25	4.51	14.70	65.80
2	5.91	3.5	2.27	3.85	13.60	66.64
4	6.6	3.98	2.28	3.45	11.80	67.50
8	6.2	4.2	2.26	5.31	12.21	68.10
10	5.3	4.3	2.24	6.10	16.10	67.80

Table 3: Optimal Values of the SRFD Modified HMA

Asphalt parameters	0%	2%	4%	8%	10%	Specifications
Stability	5.520kN	5.91kN	6.6kN	6.2kN	5.3kN	>3.5 kN
Flow	2.41mm	3.5mm	3.98mm	4.2mm	4.3mm	2 – 4 mm
Unit-weight	2.25/m^3	2.27kN/m^3	2.28kN/m3	2.26kN/m^3	2.24kN/m^3	NIL
Pa	4.51%	3.85%	3.45%	5.31%	6.10%	3 – 8%
VMA	15%	13.60%	11.80%	12.21%	16.10%	NIL
VFB	66%	67%	67.50%	68%	68%	65 – 72%

Table 4: ANOVA analysis for SRFD in HMA.

%SRFD	Stability	Flow	Bulk Density	% Air Voids	VMA	VFB
2	3.65	3.38	2.278	4.58	17.79	74.26
4	3.9	3.2	2.287	4.31	17.57	75.47
8	7.02	2.75	2.276	3.98	17.85	77.7
10	5.02	2.43	2.277	3.94	17.91	78
P value	0.517292	0.062005	0.030184	0.229759	3.48E-05	7.21E-11
F Calc.	0.458797	4.700528	6.916205	1.690355	68.14865	1978.183
F Critical	5.317655	5.317655	5.317655	5.317655	5.317655	5.317655
Remarks	No Significant effect	No Significant effect	Have Significant effect	No Significant effect	Have Significant effect	Have Significant effect

Table 5: Marsha Stability, and Flow and Marshall Quotient for SRFD.

%SRFD	Stability (KN)	Flow(mm)	Marshal Quotient (KN/mm)
2	3.65	3.38	1.08
4	3.9	3.2	1.22
8	7.02	2.75	2.55
10	5.02	2.43	2.07

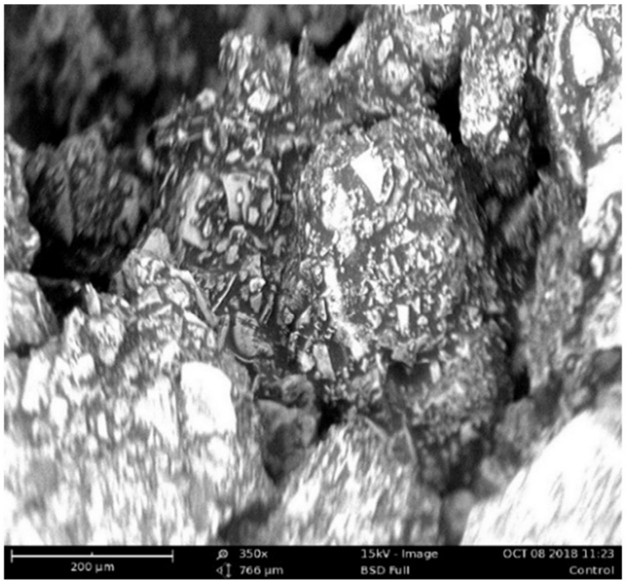


Figure 1: Electron microscopy for control HMAs mix

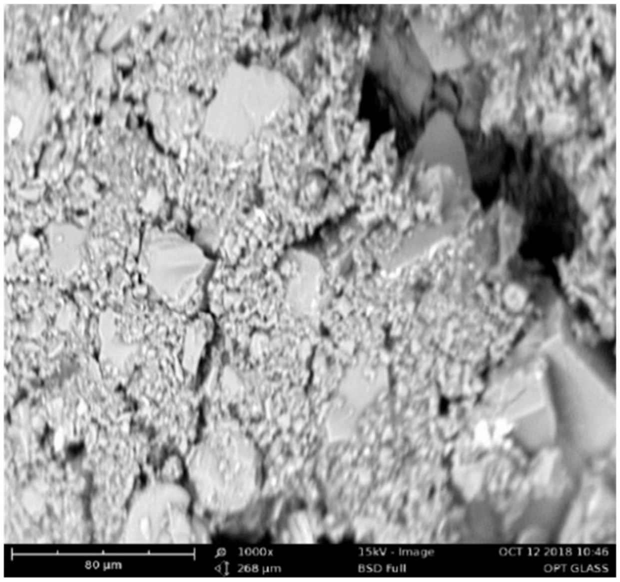
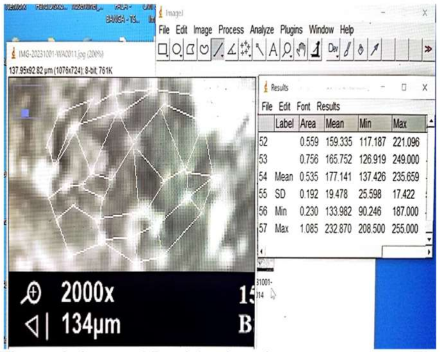


Figure 2: Electron microscopy for SRFD mix



	Label	Area	Mean	Min	Max
52		0.559	159.335	117.187	221.096
53		0.756	165.752	126.919	249.000
54	Mean	0.535	177.141	137.426	235.659
55	SD	0.192	19.478	25.598	17.422
56	Min	0.230	133.982	90.246	187.000
57	Max	1.085	232.870	208.500	255.000

Size (µm^2): 0-Infinity
☐ Pixel units
Circularity: 0.00-1.00
Show: Nothing
☐ Display results ☐ Exclude on edges
☑ Clear results ☐ Include holes
☐ Summarize ☐ Overlay
☐ Add to Manager ☐ Composite ROIs

Figure 3: Image J Particles length measurement **Figure 4:** Image J Particles Area measurement

Table 6: Image J Particles Length and Area measurement Results.

Label	Area	Mean	Min	Max	Angle	Length
	1150650	208.303	151.366	255	-35.538	9403.352
	752348	215.267	174.107	255	-125.272	6099.537
	1298169	181.152	128.517	254	12.6	10578.66
	1445688	211.316	180.113	255	-17.319	11831.98
	929371.1	196.334	138.871	254.657	102.031	7575.287
	501565.3	208.171	153.259	252	-72.121	3956.234
	693340.3	201.378	154.299	251.295	23.199	5549.956
	1298169	192.621	130.19	252	16.763	10528.34
	722844.2	207.415	171.094	255	-112.249	5774.023
	855611.5	222.354	166.316	251	-6.009	6961.326
Mean	964775.7	204.431	154.813	253.495	-21.392	7825.87
SD	315030.2	11.927	18.185	1.706	68.236	2615.615
Min	501565.3	181.152	128.517	251	-125.272	3956.234
Max	1445688	222.354	180.113	255	102.031	11831.98

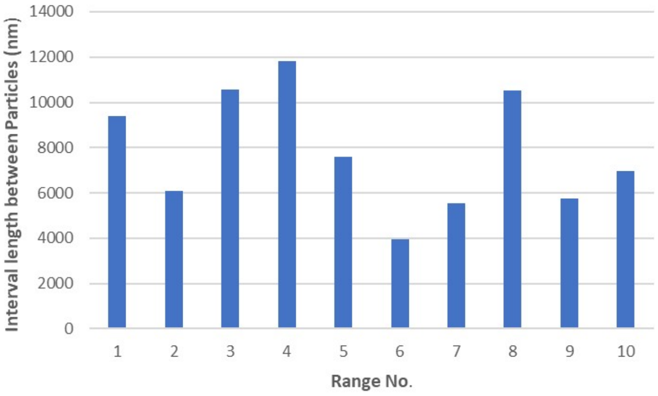


Figure 5. Image J Particles measurement bar chart

Measuring the Euclidean distance between the centroids or edges of particles. Several ImageJ functions can be used to calculate the distance between particles once they have been identified. Measuring the Euclidean distance between the centroids or edges of particles is one method. Regarding the data analysis, After the distances were measured, the data was analyzed to determine the significance of the particle distances and their distribution in the modified asphalt. Using ImageJ to analyze particle area measurements in modified asphalt requires following certain procedures to measure and evaluate the characteristics and distribution of particles in SEM images. Regarding the data analysis, After the distances were measured, the data was analyzed to determine the significance of the particle distances and their distribution in the modified asphalt. Using ImageJ to analyze particle area measurements in modified asphalt requires following certain procedures to measure and evaluate the characteristics and distribution of particles in SEM images. Table 6 and Figure 5 outline of the analysis results (ASTM

E986-04. (2017).

Conclusion

This study confirms the suitability of steel rolling furnace dust (SRFD) as a viable additive in hot mix asphalt (HMA) production. The materials used to include bitumen, aggregates, mineral filler, and the elemental/oxide composition of SRFD complied with the specifications of the Federal Ministry of Power, Works, and Housing (FMPW&H, 2016), validating their application in asphalt pavement construction. The optimal bitumen content was determined to be 5.4%, with all key mix design parameters (stability, flow, VMA, VFB, and air voids) falling within the acceptable limits defined by the General Specification for Nigerian Roads and Bridges (2016). The incorporation of SRFD enhanced the mechanical performance of the asphalt mix, as evidenced by increased bulk density and improved stability values ranging from 5.4 kN (control) to 6.61 kN (modified). Statistical analysis using one-way ANOVA indicated that SRFD did not significantly affect the mean square variance for stability, flow, and air voids ($p > 0.05$), although VMA and VFB significantly influenced unit weight. Regression analysis yielded coefficients of determination between 76% and 99%, demonstrating strong predictive validity. The Marshal Quotient of 2.55 further supports the structural integrity of SRFD-modified asphalt. Microstructural evaluation via SEM ImageJ analysis revealed a broader dispersion of particle distances in the SRFD-modified HMA, with a mean particle length of 7,825.87 µm and area of 964,775.7 µm^2. In contrast, the control mix exhibited more uniform particle distribution, with a mean length of 235.659 µm and area of 259.09 µm^2. These findings suggest that SRFD contributes to enhanced internal structure and mechanical resilience, supporting its potential for sustainable and durable road construction.

REFERENCES

ASTM D5 / D5M-20. (2020). *Standard Test Method for Penetration of Bituminous Materials.* West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

ASTM D113-17. (2017). *Standard Test Method for Ductility of Asphalt Materials* (Vol. 04.03). West Conshohocken, Philadelphia.PA: American Society for Testing and Materials (ASTM) International. Retrieved from www.astm.org

ASTM D36 / D36M-14. (2020). *Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus)* (Vol. 04.04). West Conshohocken, PA: American Society for Testing and Materials (ASTM) International. Retrieved from www.astm.org

ASTM D92-18. (2018). *Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester* (Vol. 05.01). West Conshohocken, PA: American Society for Testing and Materials (ASTM) International. Retrieved from www.astm.org

ASTM D70 /D70M-21. (2021). *Standard Test Method for Specific Gravity and Density of Semi-Solid Asphalt Binder (Pycnometer Method).* West Conshohocken, PA: American Society for Testing and Materials (ASTM) International. Retrieved from www.astm.org

ASTM C131 / C131M-20. (2020). *Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine.* West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

ASTM D4791-19. (2019). *Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate.* West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

ASTM C127-15. (2015). *Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate.* West Conshohocken, PA: American Society for Testing and Materials (ASTM) International. Retrieved from www.astm.org

ASTM D2042-15. (2015). *Standard Test Method for Solubility of Asphalt Materials in Trichloroethylene.* West Conshohocken, PA: American Society for Testing and Materials (ASTM) International. Retrieved from www.astm.org

ASTM E986-04. (2017). *Standard Practice for Scanning Electron Microscope Beam Size Characterization.* West Conshohocken, PA: American Society for Testing and Materials (ASTM) International.

AASHTO T 166. (2016). *Standard Method of Test for Bulk Specific Gravity (Gmb) of Compacted Asphalt Mixtures Using Saturated Surface-Dry Specimens.* Washington, DC: American Association of State Highway and Transportation Officials (AASHTO).

Cristiana, Z., Z.orica, B., Elena, V.S & Auroraanca, P.2010, Characterization of Steel Mill Electric-Arc Furnace Dust. *Advances in Waste Management 139-143.*

Dana, A., Illutiu, V., Claudiu, A.,Elena, M. & Cornel, S. (2017), Reserch on the Characterization of the Oily Mmill Scale for Natural Resources Conservation ,Procedia Engineering 181 (2017) 439 – 443

Gaballah,, M,. Zikry A. F., Khalifa, M. G., Farag, A. B., El-Hussiny, M. E. H., & Shalabi (2013). *Production of Iron from Mill Scale Industrial Waste via Hydro* N. A. *gen,* Open Journal of Inorganic Non-metallic Materials Vol. 3 No 3(2013), Article ID:34558, 6 Pages, DOI: 10.4236/ojinm.2013.33005.

Nur Mustakiza Zakaria[a], Mohammad Kamal Hassan[a], Ahmad Nazrul Hakimi Ibrahim[a], Sri Atmaja P. Rosyidi[b], Nur Izzi Md. Yusoff[a], Abdullahi Ali Mohamed[c], Norhidayah Hassan[d] The Use of Mixed Waste Recycled Plastic and Glass as an Aggregate Replacement in Asphalt Mixtures, Jurnal Teknologi · January 2018 DOI: 10.11113/jt.v80.11147*

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