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Investigating the Effects of Maximum Size of Aggregate on Rutting Potential of Stone Mastic Asphalt

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Abstract

Rutting in hot climatic areas and on heavy trafficking roads is the most common form of distress that has been addressed in the past by different techniques. Stone mastic asphalt has been introduced to resist rutting, first time in the pavement construction history of Pakistan that requires indepth laboratory investigation on materials and performance parameters. The main objective of the study was to investigate the influence of maximum size on the permanent deformation characteristics of stone mastic asphalt particularly at high temperatures. Rutting potential of four stone mastic asphalt concrete mixtures prepared with four nominal maximum sizes of aggregates i.e. 9.5 mm, 12 mm, 19 mm & 25.4 mm and tested using Wheel Tracker at 25, 40 and 60^{o}C has been investigated. A regression model has also been proposed that relates rut depth with number of load cycles, temperature and maximum size of the aggregates. **.** *The study reveals that the rutting susceptibility of stone mastic asphalt for any number of loading passes is a function of the maximum size of the aggregate and the test temperature. It was further revealed that rutting increases with an increase in temperature and decreases with an increase in aggregate size.*

Key Words: *Flexible Pavement, Bitumen, Stone Mastic Asphalt, Permanent Deformation, Wheel Tracker.*

1. Introduction

According to Highway department, 2001[1], stone mastic asphalt (SMA) is a stone-on-stone like skeletal structure of gap graded aggregate, bonded together by mastic, which actually is higher binder content, filler and fiber to reduce the binder drain. This structure improves the strength and the performance of SMA even higher than the dense graded and open graded asphalt mixtures**.** High percentage of binder content is important to ensure the durability and laying characteristics of SMA [2].

Muniady and Bujang, [3] concluded that several polymers especially the cellulose fibers have been used in the past to enhance the performance of bitumen in the SMA in terms of rut or fatigue resistance. Mahrez et al. studied the fatigue and deformation properties of Glass fiber reinforced SMA mixtures and concluded that this fiber had showed consistent results. It was also reported that addition of fiber did affects the properties of bituminous mixtures, by decreasing its stability and an increase in the flow value as well the voids in the mixtures. Glass fiber also showed the potential to resist structural distresses that occur in road pavement as result of increased traffic loading [4].

Bernd et al. reported that addition of cellulose fiber (0.3% by weight of the mixture) has no effect on chemical structure of binders and it only enhance the physical property of the bitumen [5]. Cellulose fibers in the form of pellets restrain bitumen within the aggregate skeleton prior to compaction. That is why SMA is being considered a best alternative in terms of longer life bituminous material, low noise & smooth riding quality mixes, and better return on investment [6].

Goh et al. 2011, used dynamic modulus testing and studied the effects of voids in coarse aggregates to ascertain SMA mixtures rut potential in the field [7]. Obert concluded that SMA mainly contains bitumen, filler, sand, stabilizing agents and between 2-4% by volume of air voids [8]. Hafeez et al. investigated the high temperature response asphalt concrete mixtures against rutting and concluded that coarser gradation and polymer modified binder enhance their rut resistance [9].

Current study investigated the influence of aggregate size on the rutting susceptibility of SMA mixtures. Binder types, binder content and air voids were kept almost at the same level. The objective of this research was to investigate the influence of maximum size of aggregate on rut depth of SMA under high temperature using a wheel tracker.

2. Experimental Program

Four typical SMA gradations were choosen to investigate the influence of sizes on rutting potential as reported in Table 1. Three gradations i.e. 25.4, 19 and 12mm nominal maximum size (NMS) were taken from AASHTO MP 8-2003[10] while fourth gradation with 9.5mm NMS was taken from Austraods, 2004[11]. The designed bitumen content in the SMA mixtures was ranges from 6 to 7 % by mass of total mix with 0.3% of fiber content by mass of total mix.

Table 1 Typical aggregate grading used for SMA mixtures

Sieve Size (mm)	% Passing (by mass) Nominal Maximum Aggregate Size (NMS)			
	Size 25.4 mm	Size 19 mm	Size 12 mm	Size 9.5 mm
25.00	100	-	-	-
19.50	90-100	100	-	-
12.50	50-88	90-100	100	-
9.50	25-60	50-80	70-95	100
4.75	20-28	20-35	30-50	85-100
2.36	16-24	16-24	20-30	30-62
1.18	-	-	-21	16-28
0.6	-	-	-18	14-24
0.30	-	-	-15	-
0.075	8-11	8-11	8-12	8-12
AC (%)	6.2	6.4	6.7	7.1
Fiber (%)	0.3	0.3	0.3	0.3

Single source of aggregates were used to avoid the influence of change in the properties of aggregate to mixture's performance. Figure 1 show their typical percentages used in the mixtures.

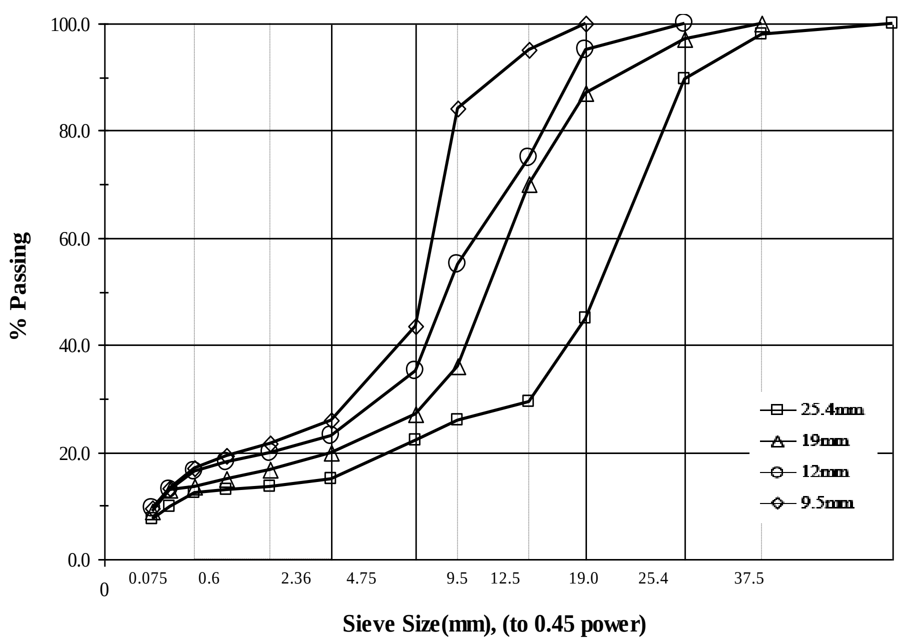

Fig.1 Selected Aggregate Gradations for SMA Mixtures

Stone Mastic Asphalt generally requires more binder content than conventional dense graded mixtures and addition of fiber enhance holding capacity of binder within the aggregate skeletal. Mastic for SMA, which contains binder, filler and fiber was prepared with J.Rettenmaier & Sohne (JRS) Germany, cellulose fibers, Viatop and PG 58 asphalt cement was used for preparation of mixtures.

Superpave mix design procedure was performed to prepare four mixes. Mixing of aggregate with binder was carried out at a working temperature of 145°C $\pm$ 5°C. Air voids in the design mixtures were from 2 to 4% with 17% voids in mineral aggregate and a minimum tensile strength ratio of 0.7.

Specimens of 40.3cm x 40.3cmx5.0cm size, weighing 12.5kg were prepared using a roller compacter as shown in Figure 2. The compaction pressure and number of roller compactor passes were selected to control air voids of SMA.

Wheel tracking device as shown in Figure 3; assesses the resistance to rutting of asphaltic material under conditions which simulate the effects of traffic and environment by measuring relative percentage reduction in thickness of the specimen in the wheel path. A loaded wheel (700 ± 20 N) tracked with simple harmonic motion through a distance of 305mm on specimens under specified conditions of speed (53 passes per minute) and temperatures, while the development of the rut was monitored with linear variable differential transducers [9]. Specimens in replicate were tested at 25, 40 and 60°C under total wheel passes of 10,000.

Fig. 2 Slab specimen preparations on Roller Compacter [12]

3. Results and Discussion

Development of rut depth with the passage of wheel cycles have been shown in Figure 4 that showed the load repetitions has direct relationship with increase in the rut depth. Trends have clearly shown that the slope of plots increases with decrease in the maximum size of aggregate. One of the reasons may be loss of interlocking mechanism with decrease in the size of aggregates, which ultimately reduces the stiffness of mixtures at higher temperatures.

Fig. 3 Wheel tracker machine [12]

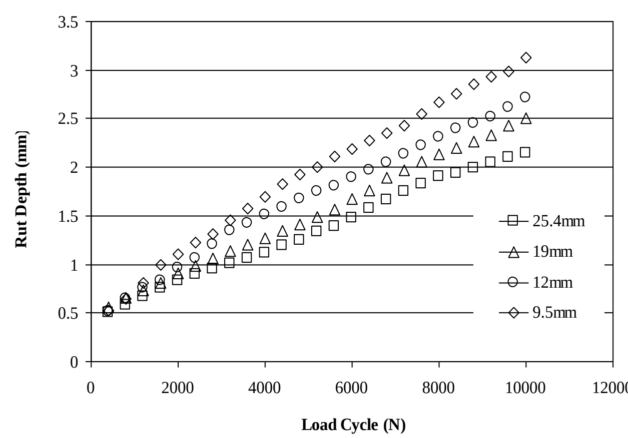

Fig.4a Influence of load cycles on rut depth at 25°C

Table 2 summarizes the results of rut depth shown in Figure 4. At 60°C temperature, SMA mixture with 25.4mm NMS showed only 6.6 mm rut depth value, which was minimum compared with other mixtures. SMA with 9.5mm NMS showed a rut depth of 15.14mm at 60°C.

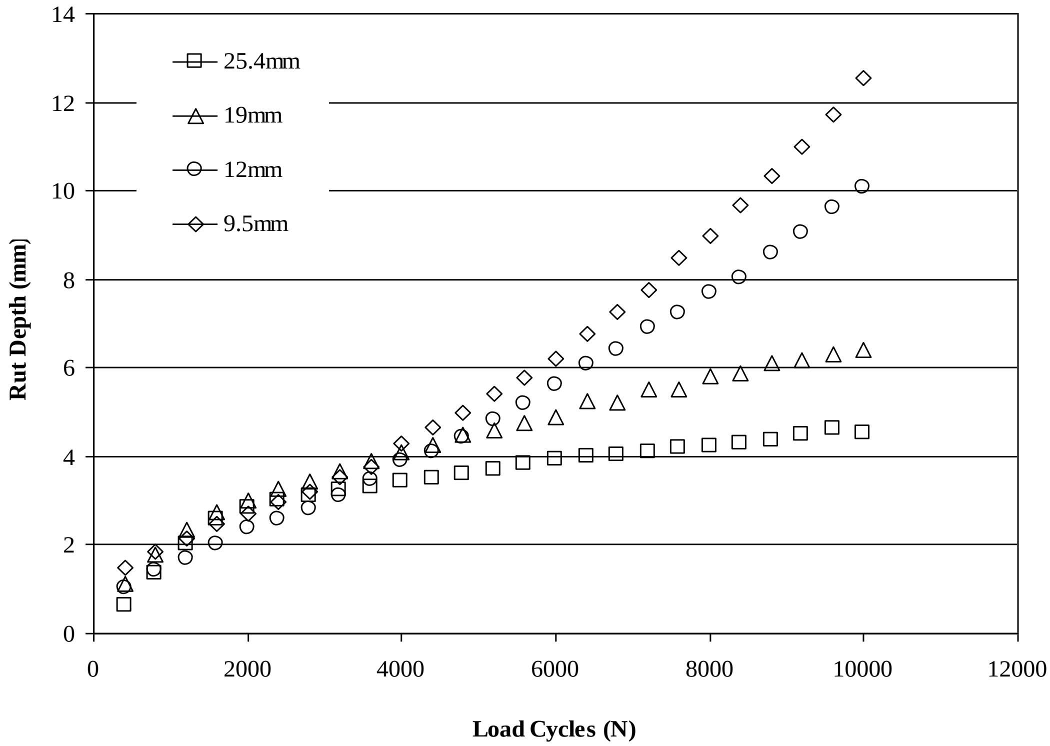

Fig.4b Influence of load cycles on rut depth at 40°C

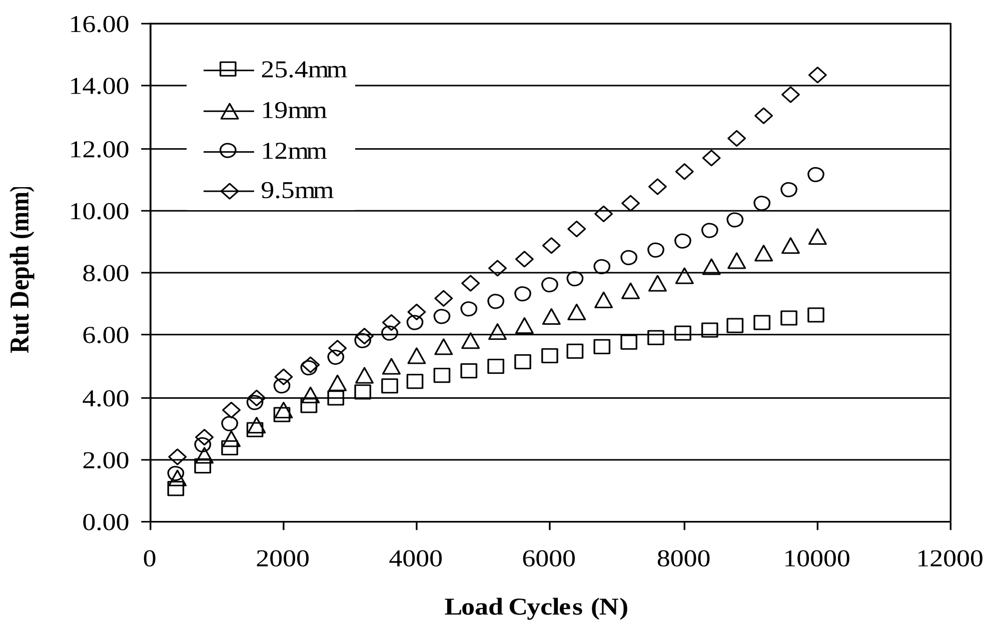

Fig.4c Influence of load cycles on rut depth at 60°C

Table 2 Rut Depth in SMA Mixtures

NMS Size (mm)	Rut Depth of Mixtures (mm)		
	25°C	40°C	60°C
25.4	2.14	4.67	6.6
19	2.50	6.95	9.03
12	2.71	9.97	12.17
9.5	3.13	12.7	15.14

4. Research Analysis

Rut formation data was plotted on log-log space to obtained linear relationship and to compute the regression constants that help in accessing the rut resistance of mixes. Relationships between load repetitions and rut depth were developed. Both intercept coefficient "a" and slope coefficient "b" were computed and reported in Table 3.

Results of Table 3 have also been presented in bar chart to access the influence of maximum size on the linear regression coefficients. It can be observed from Figure 5 that both the coefficient increases with decrease in the maximum size of aggregate. Slope coefficient, also known as the rut rate, showed significant increase particularly at 60°C. It can be observed that both the coefficients increase with decrease in aggregate size.

5. Development of Rut Prediction Model

A regression model was developed to investigate the influence of aggregate size on the rut depth that determines the relative importance of each independent variable on the resultant rut value of the asphalt mixtures under the cyclic loading. Independent variables were interacted individually and then in groups to investigate their relationship with the rut depth measured from the wheel tracker. Using the Microsoft Excel Solver (MES) tool, least square regression analysis was run on the entire data. Non linear regression coefficients (a_1, a_2, a_3, a_4) were then obtained. The model was then statistically evaluated on the basis of the goodness-of-fit parameters i.e. coefficient of determination R^2; standard error of estimate, S_e; and relative accuracy, S_e/S_y. The plots between the measured and predicted rut depth along with model statistics have been shown in Figure 6.

Table 3 Details of regression coefficients

NMS Size (mm)	Intercept Coefficient			Slope Coefficient		
	25°C	40°C	60°C	25°C	40°C	60°C
25.4	4.3155	4.323	4.617	0.2	0.234	0.235
19	4.370	4.492	4.709	0.202	0.239	0.241
12	4.436	4.558	4.764	0.223	0.246	0.271
9.5	4.468	4.679	4.804	0.240	0.251	0.284

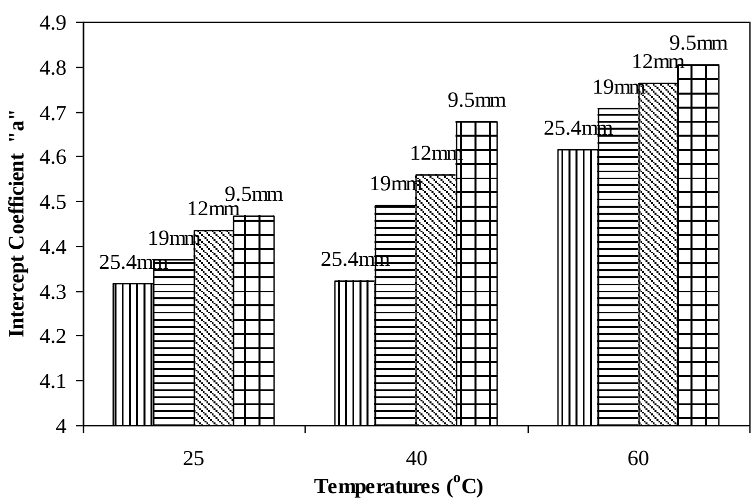

Fig.5a Variation in regression coefficients "a"

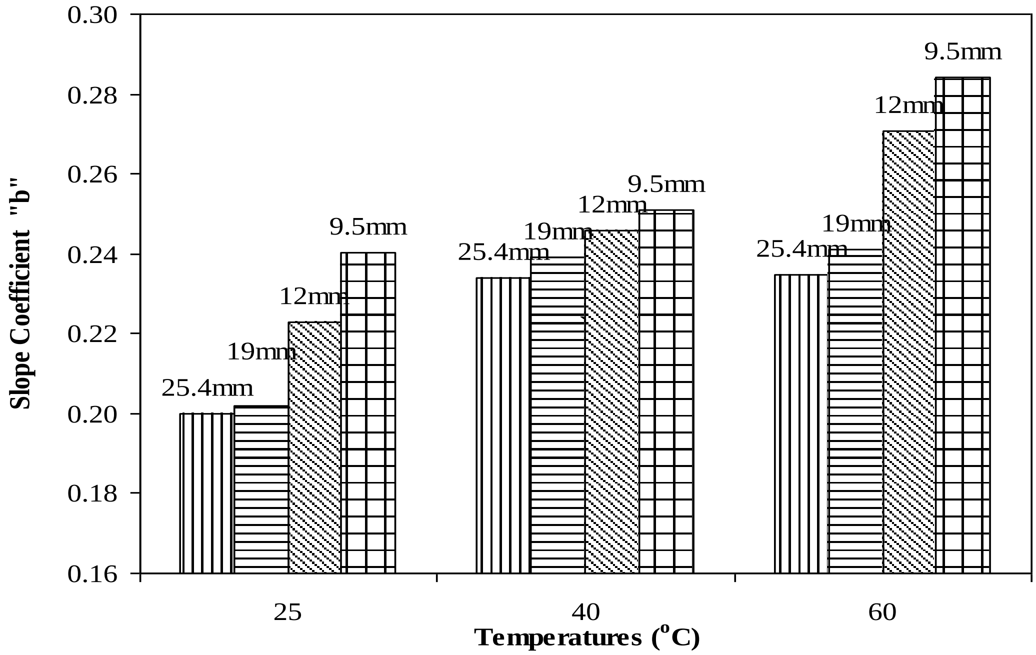

Fig.5b Variation in regression coefficients "b"

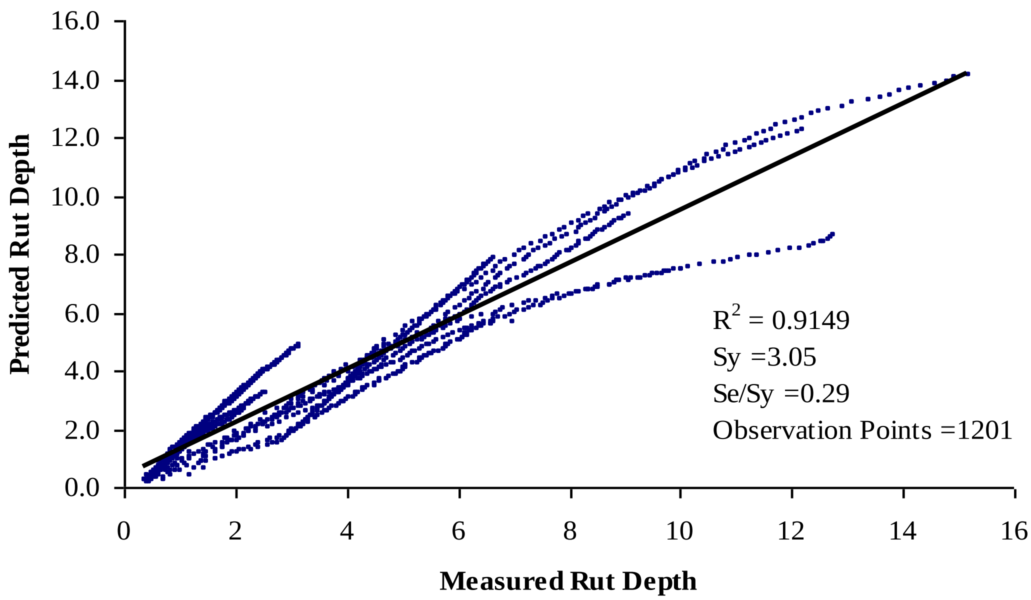

Fig. 6 Agreement Between measured and predicted rut depth

The regression model that has maximum coefficient of determination and other statistic parameters is as follow;

$$h = a_1 \frac{T^{a_2} N^{a_3}}{D^{a_4}} \qquad (1)$$

Where:

h = rut depth (mm)
T = temperature (^oC)
N = load repetitions
D = nominal maximum size of aggregate,
a_i = non linear regression coefficients (a_1=0.0008, a_2=1.22, a_3=0.67, & a_4=0.60)

One can observe that the value of non-linear coefficients for both the aggregate size and load cycles in the above model are almost equal. The results support the fact that the size of aggregate has equal magnitude but opposite influence on the rut depth as of load cycles. The above equation can be presented as;

$$h = 0.0008 \frac{T^{1.22} N^{0.67}}{D^{0.60}} \qquad (2)$$

Percentage error between the observed and the predicted rut depth were then computed to measure the range of percentage difference. Histogram as shown in Figure 7 infers that 90% of percentages differences are within ± 1% that also indicate a good prediction model.

6. Conclusions

Based on testing and analysis of results in this research study, following conclusions have been drawn;

- With increase in the size of aggregate, rut value decreases. Temperature has significant influence on the rut depth of SMA, especially mixtures with smaller size particles.
- Regression coefficients i.e. intercept coefficient “a” & slope coefficients “b” depicts the influence of temperature and aggregate size on rut value.
- The proposed model depicts rut depth of the SMA mixture with an excellent agreement and rut depth relates with load cycles, temperature and maximum size of the aggregate.

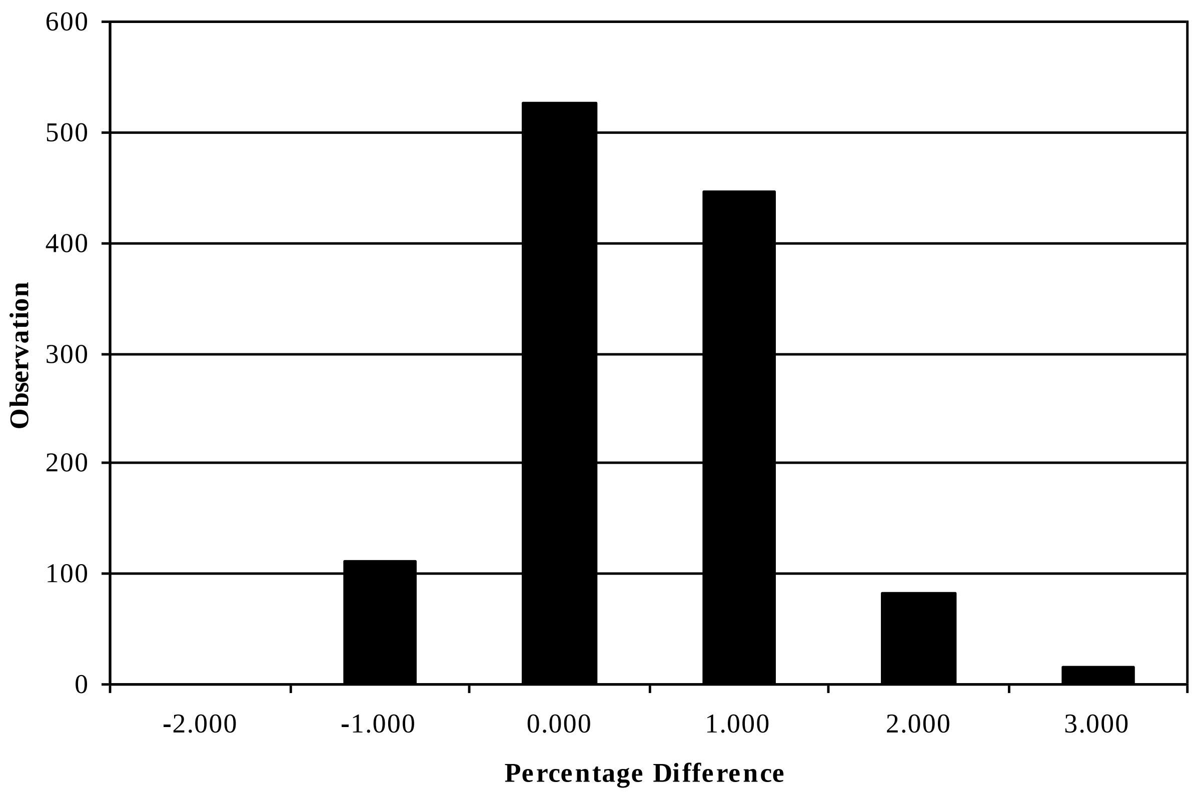

Fig. 7 Percentage Differences between the observed and the predicted rut depth.

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