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A mathematical model for predicting stripping potential of Hot Mix Asphalt

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HIGHLIGHTS

- Parametric studies should be directed to find any interaction terms.
- Lime content had the greatest effect on TSR increase.
- PPSS 4.75 mm had the greatest effect on TSR decrease.

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ABSTRACT

Stripping – the most important mode of Hot Mix Asphalt (HMA) failure – is a problematic issue in the pavement performance and its maintenance. Identification and quantification of the pertinent parameters influencing on stripping process is a prerequisite for dealing with it effectively. Previous studies on stripping potential of HMA have focused on this issue based on empirical/semi-empirical models. In the present work Response Surface Methodology (RSM) was used for the study and optimization of pertinent factors, namely bitumen content employed, grading and lime content, in the stripping process of HMA. Tensile Strength Ratio (TSR) was chosen as the response for the evaluation of stripping potential of HMA using a Central Composite Design (CCD). The statistical analyses showed that second order polynomial models can successfully describe the relationship between the response and factors and the maximum Tensile Strength Ratio (TSR) is achieved at 5.73% bitumen content, 1.84% lime content and 65.30% of the materials passing sieve size 4.75 mm.

1. Introduction

1.1. Background

Hot Mix Asphalt (HMA) made from certain materials may be sensitive to the presence of water in the finished pavement. Water trapped in the pavement structure may cause a separation of bitumen from aggregate and/or failure within the bitumen itself. This phenomenon is often referred to as stripping [1]. Stripping change mechanical properties of pavement and gradually decrease the strength of the material leading to rutting, corrugation, shoving, ravelling, cracking, etc. [2]. Stripping phenomenon leads to a premature rehabilitation and higher maintenance cost [3,4].

Various kinds of test procedures have been proposed by researchers to assess moisture sensitivity of asphalt mixtures [1,2,5–9], but it appears that there is no global agreement among researchers on a single procedure for evaluating this distress mechanism [2]. Among the several common test procedures, such as boiling test, Marshall and indirect tensile tests (Modified Lottman Test), some researchers and institutions [10–14] believe that the latter is more capable of predicting stripping phenomenon. Indirect tensile test (AASHTO T283) is a test method that can be used to determine whether the material is prone to stripping and also to measure the effectiveness of additives [2,15].

There are many methods that can be used to prevent or control stripping phenomenon. One the most common is the use of anti-stripping additives such as liquid anti-stripping or hydrated lime. Researchers found that the mixes containing hydrated lime and

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liquid anti-stripping agent are stiffer, less susceptible to rutting, moisture damage and cracking and have improved fracture toughness at low temperatures [2], also, they indicated that for a single source of aggregate and bitumen, hydrated lime has the most prominent effect on increasing moisture resistance [2]. A literature review reveals that around 1–1.5% hydrated lime is an optimum value that can prevent or control stripping potential of asphalt mixtures [16–18].

The physical and mechanical properties of asphalt mixtures depend on mix design, traffic loading and environmental parameters [3,19–21]. Two of the relevant parameters, which affect the mechanical properties of HMA and consequently its moisture resistance, are the aggregate grading and bitumen content (BC) [22,23]. Khodaii et al. reported that decreasing the aggregate size and increase in mastic asphalt would increase the stripping potential of hot mixes asphalt with dense gradation [16]. Also, they found that increasing the mastic asphalt would decrease the stripping potential of stone matrix asphalt (SMA) [17].

1.2. Response Surface Methodology

Response Surface Methodology (RSM) is a statistical approach used for deriving a mathematical relation between responses and factors as well as the analysis of the problems [24,25]. Second order equations are commonly deployed to model the relationship between responses and factors. Such models, albeit approximate, can be used to predict response value for a given variable, determine the significance of the factors and to estimate the combination of the factors that can yield to a maximum or minimum value of the response over a certain region of interest [24–26].

This methodology has recently been employed by researcher in the field of pavement materials to investigate the effects of various factors such as grading and lime content on stripping potential [16,17], frequency and temperature on permanent deformation [27] and bitumen content, specimen diameter, test temperature and load duration on resilient modulus of HMA [28]. Also, Kavussi et al. evaluated the interactive effects of lime and Zycosoil, warm additive content and grading on stripping potential of warm mix asphalt (WMA) using RSM [18,29]. Hamzah et al. [30] employed this methodology to determine the optimum binder content of warm mix asphalt incorporating Rediset.

1.3. Center composite design

To be able to conduct a response surface, it is essential to have an appropriate choice of design of experiments. The most common design for fitting a second order model is the central composite design (CCD) which consists of 2^k runs (k is the number of factors), $2k$ axial (star) runs and some center runs (Fig. 1) [25,26]. Using fractional factorial designs (FFD) such as CCD, can show any interactions between parameters with the use of far less experiments compared to full factorial design [26].

1.4. Objective of study

The aim of the present study was to examine the effects of the percent of materials passing sieve size 4.75 mm (PPSS 4.75 mm), bitumen content (BC) and lime content (LC) on stripping potential of dense graded HMA made with siliceous aggregate and 60/70 penetration grade bitumen, as well as interactions between them, using proper methodology, namely RSM. A half fractional factorial center composite design was selected as the design matrix since it allows the identification of first order interaction between factors and provides second order polynomial models, which can be employed to predict optimum level of these parameters.

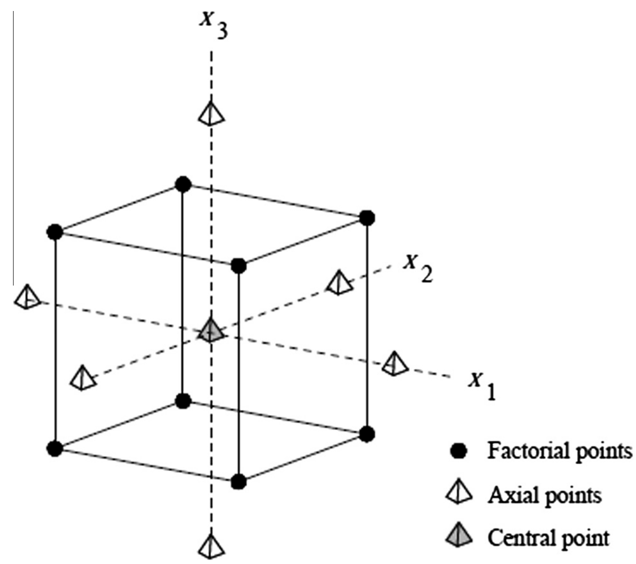


Fig. 1. Central composite design for 3 design variables at 2 levels [26].

2. Materials

Three grading levels of one aggregate type, containing 85%, 70% and 55% passing 4.75 mm sieve size were selected according to ASTM D3515 [31]. These are shown in the dense gradation curves of Fig. 2. The grading levels were named as fine, medium and coarse grading. Tables 1 and 2 show physical properties of the siliceous aggregates used in the research. The filler was siliceous and the percentages of the filler used were 10%, 6% and 2% for fine, medium and coarse grading respectively. Furthermore, different percentages of hydrated lime (i.e. 1.5% and 3%) utilized as the anti-stripping were in addition to the filler content already present in the aggregate mix.

AC 60/70 penetration grade bitumen was used to prepare all mixes. Properties of the bitumen are presented in Table 3.

3. Experimental methods

3.1. Indirect tensile strength test

The aim of the modified Lottman Test (AASHTO T283) [15] is to evaluate susceptibility characteristics of the mixture to water damage. The test is performed by compacting specimens to an air void level of six to eight percent. Three specimens were selected as control and tested without moisture conditioning, and three more specimens were selected to be conditioned by saturation with water (70–80% saturation level). The specimens were then tested for indirect tensile strength by loading the specimens at a constant rate (50 mm/min) and measuring the force

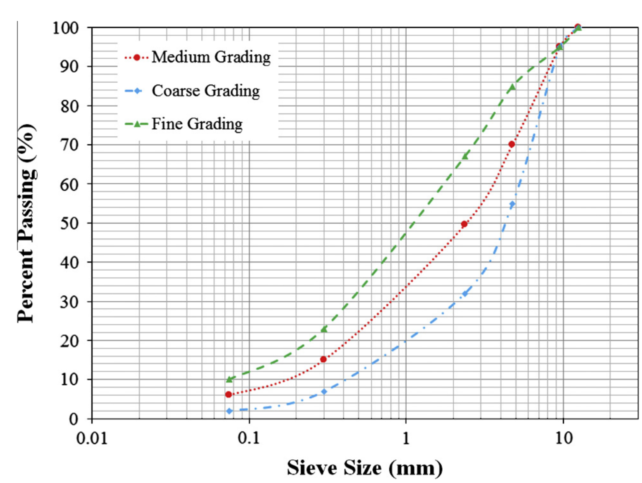


Fig. 2. Grading size distribution of the coarse, medium and fine aggregates.

Table 1
Properties of the siliceous aggregate used.

Test	Standard	Values (%)	MS-2 specifications (%)
LA abrasion loss	AASHTO T96	19	<30
Crushed in one face	ASTM D5821	100	–
Fractured particles in two face and more	ASTM D5821	93	90<
Coating of aggregate	AASHTO T182	97	95<
Flakiness	BS-812	20	<25
Sand equivalent	AASHTO T176	75	50<
Sodium sulphate soundness	AASHTO T104	2.90	<12
		0.40	<8

Table 2
Engineering properties of aggregate used.

Fraction	Standard	Specific gravity (g/cm^3)		Absorption
		Apparent	Bulk	
Retained on 2.36 mm (No. 8)	AASHTO T85	2.62	2.52	1.58
Passed from 2.36 mm and retained on 0.075 mm	AASHTO T84	2.62	2.51	2.2
Passed from 0.075 mm (No. 200)		–	2.68	–
Bulk specific gravity on blended aggregate		–	2.53	–

Table 3
Properties of bitumen used in the study.

Test	Standard	AC 60/70
Ductility at 25 °C (cm)	ASTM D113	100
Penetration at 25 °C, 100 g (0.1 mm)	ASTM D5	61
Softening point (°C)	ASTM D36	50.1
Specific gravity at 25 °C	ASTM D70	1.016
Viscosity at 135 °C (Pa s)	ASTM D4402	0.51

required to break them. The tensile strength of the conditioned specimens was compared with the control specimens to determine the Tensile Strength Ratio (TSR). The tensile strength ratio is calculated as follows:

$$\text{Tensile Strength Ratio (TSR)} = \frac{S_2}{S_1} \times 100 \quad (1)$$

where
S_1 = average indirect tensile strength of the dry subset (kPa),
S_2 = average indirect tensile strength of the conditioned subset (kPa).

3.2. Design of experiments

To investigate the effects of pertinent parameters on HMA properties, RSM was employed. A CCD was adopted in this research to study three factors at three levels. Seventeen experimental runs including three face centers were generated with three factors and three levels by the principle of RSM using MINITAB Release 15 [32]. The CCD design matrix employed which includes the different levels of factors, is presented in Table 4.

A quadratic polynomial regression model proposed by Montgomery [25] as shown in Eq. (2) was chosen for predicting the response variable in terms of the four independent variables chosen for study:

$$Y = b_0 + \sum_{i=1}^{3} b_i X_i + \sum_{i=1}^{3} b_{ii} X_i^2 + \sum_{i=1}^{2}\sum_{j=i+1}^{3} b_{ij} X_i X_j \quad (2)$$

In this equation Y is the response variable (i.e. ITS_{dry}, ITS_{sat} and TSR) and b_0, b_i, b_{ii}, and b_{ij} are constant coefficients of intercept, linear, quadratic and interaction terms, respectively, and X_i and X_j represent the three independent variables (i.e. bitumen content, grading and lime content). The experiments were carried out with two replicates and conducted in a randomized order to avoid systematic bias.

The statistical significance of the developed model as well as the effect of factor (linear, quadratic and interactive terms) was evaluated by analysis of variance (ANOVA). This procedure was carried out using MINITAB Release 15.

4. Results and discussion

4.1. Model fitting

The values of responses at each of the 17 combination of factorial levels generated by the principles of RSM are listed in Table 4. Moreover, the statistical significance of the full quadratic models predicted is evaluated by the analysis of variance (ANOVA) as given in Table 5; the suitability of the model is confirmed by the low P value for the regression ($P < 0.1$) and the fact that the lack of fit of the model is not significant ($P > 0.1$).

At 90% confidence level, all the first order terms of the independent parameters together with second order terms of X_1, X_2 and X_3 are significant (Table 6). Moreover, the interactive terms of X_1X_2 and X_1X_3 are statistically significant in case of TSR; additionally, the interactive terms of X_1X_2 and X_2X_3 in case of ITS_{dry} and X_1X_3 in case of ITS_{sat} are significant at 90% confidence level. Based on the regression coefficients calculated for the responses shown in Table 4 following polynomial regression model Eqs. (3)–(5) are proposed:

$$\begin{aligned} TSR = {} & -368.89 + 2.23X_1 + 6.18X_2 + 129.22X_3 - 0.02X_1^2 \\ & - 2.45X_2^2 - 11.91X_3^2 - 0.11X_1X_2 + 0.10X_1X_3 \\ R^2 = {} & 99.95 \end{aligned} \quad (3)$$

$$\begin{aligned} ITS_{dry} = {} & -2518.77 - 66.40X_1 + 203.37X_2 + 344.43X_3 - 0.5X_1^2 \\ & - 39.34X_2^2 - 30.01X_3^2 - 0.29X_1X_2 - 1.92X_2X_3 \\ R^2 = {} & 99.97 \end{aligned} \quad (4)$$

$$\begin{aligned} ITS_{sat} = {} & -4955.31 + 65.17X_1 + 200.88X_2 + 1151.73X_3 - 0.5X_1^2 \\ & - 40.85X_2^2 - 102.91X_3^2 + 0.32X_1X_3 \\ R^2 = {} & 99.37 \end{aligned} \quad (5)$$

where
X_1 = percent passing sieve size 4.75 mm (PPSS 4.75 mm),
X_2 = lime content (LC),
X_3 = bitumen content (BC).

Table 4
Central composite design arrangement and responses for mixtures.

Run	Factors			Response		
	Passing sieve size 4.75 mm (%)	LC (%)	BC (%)	TSR (%)	ITS_{dry} (kPa)	$ITS_{saturated}$ (kPa)
1	55	0.0	4.5	50.5	560	283
2	85	0.0	4.5	35.4	457	162
3	55	3.0	4.5	69.1	745	515
4	85	3.0	4.5	65.6	611	401
5	55	0.0	6.5	60.7	594	361
6	85	0.0	6.5	53.1	480	255
7	55	3.0	6.5	76.6	763	585
8	85	3.0	6.5	78.5	627	494
9	55	1.5	5.5	80.8	782	632
10	85	1.5	5.5	77.9	662	516
11	70	0.0	5.5	71.2	667	475
12	70	3.0	5.5	86.7	825	716
13	70	1.5	4.5	68.3	793	542
14	70	1.5	6.5	76.8	816	627
15	70	1.5	5.5	83.3	833	694
16	70	1.5	5.5	82.0	840	685
17	70	1.5	5.5	84.0	837	699

LC low level = 0%. LC mean level = 1.5 %. LC high level = 3%. PPSS 4.75 mm low level = 55%. PPSS 4.75 mm mean level = 70%. PPSS 4.75 mm high level = 85%. BC low level = 4.5%. BC mean level = 5.5 %. BC high level = 6.5%.

Table 5
ANOVA table for TSR, ITS_{dry} and ITS_{sat} values.

	DF	SS	MS	*F*-values	*P*-values
TSR					
Total	16	3104.40	–	–	–
Regression	9	3068.86	340.984	67.14	0.000
Residual error	7	35.55	5.078	–	–
Lack of fit (model error)	5	33.49	6.698	6.5	0.139
Pure error (replicate error)	2	2.06	1.03	–	–
R^2	98.85	–	–	–	–
ITS_{dry}					
Total	16	260,570	–	–	–
Regression	9	260,511	28945.7	3414.69	0.000
Residual error	7	59	8.5	–	–
Lack of fit (model error)	5	35	6.9	0.56	0.739
Pure error (replicate error)	2	25	12.3	–	–
R^2	99.98	–	–	–	–
ITS_{sat}					
Total	16	451,096	–	–	–
Regression	9	450,878	50097.6	1610.41	0.000
Residual error	7	218	31.4	–	–
Lack of fit (model error)	5	117	23.4	0.47	0.788
Pure error (replicate error)	2	101	50.3	–	–
R^2	99.95	–	–	–	–

Abbreviations: DF, degrees of freedom; SS, sum of squares; MS, mean square.

4.2. Main effect plot

According to the main effect plots presented in Fig. 3a, the influence of LC on TSR is more than that of BC and grading when each parameters moves from its low level to its mid-level. A change in the BC from low level (4.5%) to mid-level (5.5%) results in an increase in the TSR value approximately from 57% to 81% but in case of LC a change in the LC from low level to mid-level leads to an increase in the TSR value from around 55% to 80%. After that TSR decreases when BC and LC move from their mid-level to high level.

It can be observed that a variation in PPSS 4.75 mm from its low level (coarse grading) to mid-level (medium grading), leads to around 13% increase in this response and then TSR descends when PPSS 4.75 mm changes from mid to high level. In addition, it can be concluded that the optimum grading appears to be around the mid-level of 70% in PPSS 4.75 mm. Hence, the maximum TSR value was achieved at this mid-level.

Similar analyses can be carried out in the case of ITS_{dry} and ITS_{sat}. For instance, Fig. 3a and b shows that the effect of LC on increasing ITS_{dry} and ITS_{sat} is more than other parameters when each of them changes from low level to mid-level, however after that the effect of PPSS 4.75 mm on decreasing both responses (i.e. ITS_{dry} and ITS_{sat}) is considerable compare to other parameters when each of them moves from mid-level to high level.

At around 70% PPSS 4.75 mm the value of the TSR, ITS_{dry} and ITS_{sat} gained their maximum values, this could be attributed to the positive effect of optimum gradation on moisture susceptibility of the mix as well as their strength as measured by ITS_{dry} and ITS_{sat}. The optimum amount of bitumen content for this particular gradation was found to be around 5.5% as indicated in all three figures of TSR, ITS_{dry} and ITS_{sat} versus bitumen content. Maximum TSR, obtained for different lime content was at 1.5%; its effect starts to decrease when the lime content is increased from this value. This is in line with common finding of most researchers in this field [16–18].

4.3. Effects of parameters: analysis of response surface

Surface plots depict how a response variable relates to two factors based on a model equation. This is especially beneficial when there is an interaction between two parameters. The curvature of the surface plot presented in Fig. 4a and b suggest that BC–PPSS 4.75 mm and LC–PPSS 4.75 mm have interaction with each other in TSR.

At constant BC (4.5% of the mixture) an increase in the amount of PPSS 4.75 mm from low level to mid-level results in enhancement of TSR from almost 62% to 71% and after that the values of TSR decrease when PPSS 4.75 mm moves from mid-level to high level (Fig. 4a). Also, it can be observed that at a constant level of PPSS 4.75 mm (i.e. 80%) when the amount of BC increases, the value of TSR initially increases to reach $TSR_{maximum}$ (around 80%) and then the values of TSR decreases (Fig. 4a).

Fig. 4b elucidates that at constant LC (3%) when PPSS 4.75 mm changes from low level (55%) to mid-level (70%) the values of TSR climb up and then with increasing the amount of PPSS 4.75 mm from mid-level to high level the values of TSR reduces. In addition,

Table 6
Values of regression coefficients calculated.

Independent factor	*P*-value	*T*-value	Standard error	Regression coefficient
TSR				
Constant	0.000	−8.046	46.4899	−374.050
Linear				
PPSS 4.75 mm	0.043	2.461	0.9079	2.235
LC	0.059	0.059	2.252	9.626
BC	0.0	8.327	15.6306	130.163
Quadratic				
PPSS 4.75 mm	0.007	−3.716	0.0061	−0.023
LC	0.005	−4.006	0.6119	−2.451
BC	0.000	−8.655	1.3768	−11.915
Interactive				
PPSS 4.75 mm–LC	0.013	3.310	0.0354	0.117
PPSS 4.75 mm–BC	0.083	2.024	0.0531	0.108
LC–BC	0.278	−1.177	0.5312	−0.625
ITS_{dry}				
Constant	0.000	−42.629	60.0638	−2560.48
Linear				
PPSS 4.75 mm	0.000	57.120	1.1730	67.00
LC	0.000	36.823	5.5230	203.37
BC	0.000	17.431	20.1944	352.01
Quadratic				
PPSS 4.75 mm	0.000	−63.255	0.0079	−0.50
LC	0.000	−49.763	0.7905	−39.34
BC	0.000	−16.874	1.7787	−30.01
Interactive				
PPSS 4.75 mm–LC	0.000	−6.436	0.0457	−0.29
PPSS 4.75 mm–BC	0.158	−1.579	0.0686	−0.11
LC–BC	0.027	−2.793	0.6862	−1.92
ITS_{sat}				
Constant	0.000	−43.002	115.063	−4947.98
Linear				
PPSS 4.75 mm	0.000	28.921	2.247	64.99
LC	0.000	18.524	10.580	195.99
BC	0.000	29.797	38.686	1152.73
Quadratic				
PPSS 4.75 mm	0.000	−33.282	0.015	−0.50
LC	0.000	−26.972	1.514	−40.85
BC	0.000	−30.201	3.407	−102.91
Interactive				
PPSS 4.75 mm–LC	0.206	1.395	0.088	0.12
PPSS 4.75 mm–BC	0.047	2.409	0.131	0.32
LC–BC	0.628	−0.507	1.315	−0.67

this figure shows that in fine grading (i.e. PPSS 4.75 mm = 85%) when LC moves from its low level (0%) to high level (3%) the values of TSR is increased.

Similar analyses can be carried out in case of ITS_{dry} and ITS_{sat}.

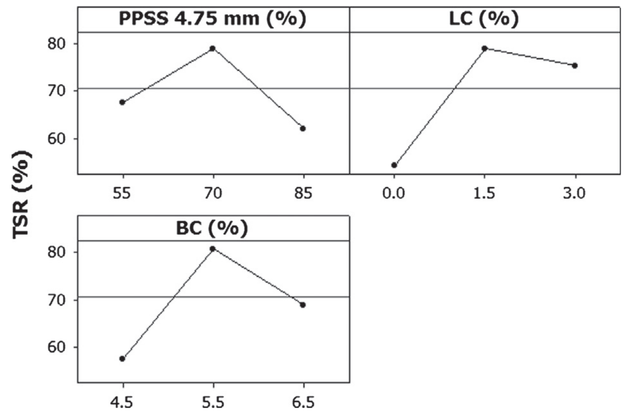
Khodaii et al. attempted to investigate the effect of three aggregate grading with different maximum nominal aggregate size. They reported that increasing the coarse aggregate and decreasing the mastic will enhance the ITS value tested in dry conditions. They also indicated that in saturated state, higher amount of mastic asphalt makes the mix more prone to stripping. This could be attributed to the fact that in mixes containing more mastic i.e. dense graded mixes, the void sizes are more minute and widely spread throughout the mix with more overall void surface area; therefore in spite of less permeability, if saturated the moisture access to the asphalt is far greater leading to more potential for stripping [17].

As mentioned in Section 2, three grading levels with the same nominal maximum aggregate size and different amount of mastic were selected and studied in this work. The optimum grading appears to be around the mid-level of 70 in PPSS 4.75 mm. Hence, it would be obvious that the maximum TSR value can be achieved at this mid-level, even though the amount of mastic in mid-level (PPSS 4.75 mm = 70%) is higher than low level (PPSS 4.75 mm = 55%). This indicates the importance of selecting a reasonable ratio for coarse aggregate to mastic in the mix. On the other hand, optimum aggregate grading plays a major role in increasing or decreasing moisture resistance of HMA.

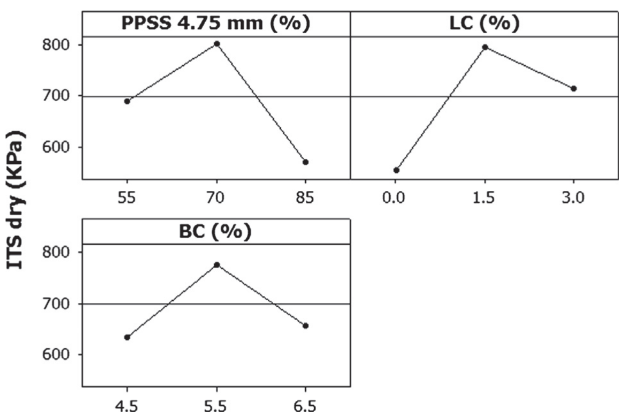
As mentioned in Section 4.1 the interactive term of BC and LC is not statistically significant in case of TSR. Also, the interactive terms of PPSS 4.75 versus BC in case of ITS dry and PPSS 4.75 versus LC and BC versus LC in case of ITS sat are not statistically significant. As a result their surface plots were not represented in Fig. 4.

5. Residual analyses

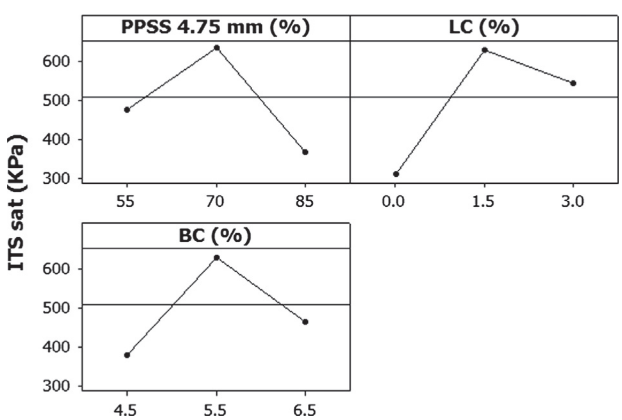
The verification of the suitability of the regression model for predictive purposes is carried out by residual analysis to confirm the normality of data [32]. The appropriate distribution of the data on both sides of the line in "residual plot" indicates the suitability of the suggested model. "Normal probability plot" and "Residual plot" are shown in Figs. 5 and 6.



(a) TSR versus PPSS 4.75mm, LC and BC



(b) ITS_{dry} versus PPSS 4.75mm, LC and BC

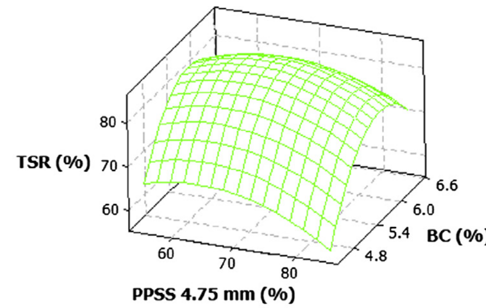


(c) ITS_{sat} versus PPSS 4.75mm, LC and BC

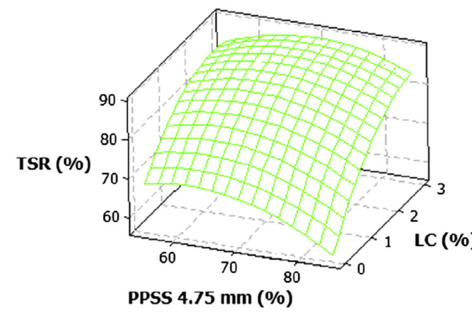
Fig. 3. Main effect plots of TSR, ITS_{dry} and ITS_{sat}. (a) TSR versus PPSS 4.75 mm, LC and BC. (b) ITS_{dry} versus PPSS 4.75 mm, LC and BC. (c) ITS_{sat} versus PPSS 4.75 mm, LC and BC.

6. Optimization of the process response

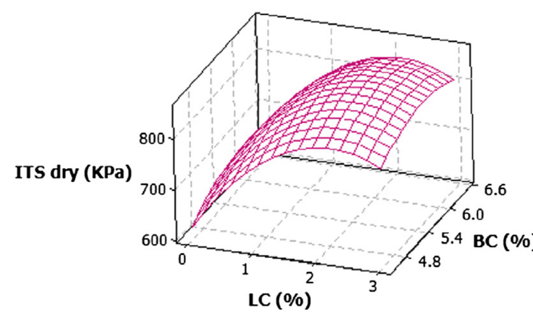
The derived models can be used for interpolation within the levels of the studied parameters to achieve the maximum (or minimum) desirable responses [16–18,29]. The aim was to achieve maximum values for TSR, ITS_{dry} and ITS_{sat}, within the factors considered in this research. The maximum value of TSR was 86.7% obtained at LC = 1.84%, BC = 5.73% and PPSS 4.75 mm = 65.30%.



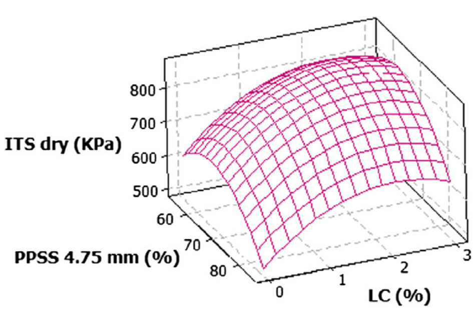
(a) TSR versus BC and PPSS 4.75 mm



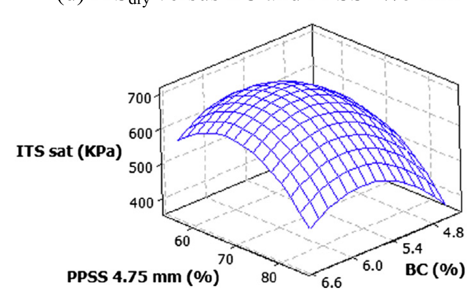
(b) TSR versus LC and PPSS 4.75 mm



(c) ITS_{dry} versus LC and BC



(d) ITS_{dry} versus LC and PPSS 4.75 mm



(e) ITS_{sat} versus BC and PPSS 4.75 mm

Fig. 4. Surface Plots of TSR, ITS_{dry} and ITS_{sat}. (a) TSR versus BC and PPSS 4.75 mm. (b) TSR versus LC and PPSS 4.75 mm. (c) ITS_{dry} versus LC and BC. (d) ITS_{dry} versus LC and PPSS 4.75 mm. (e) ITS_{sat} versus BC and PPSS 4.75 mm.

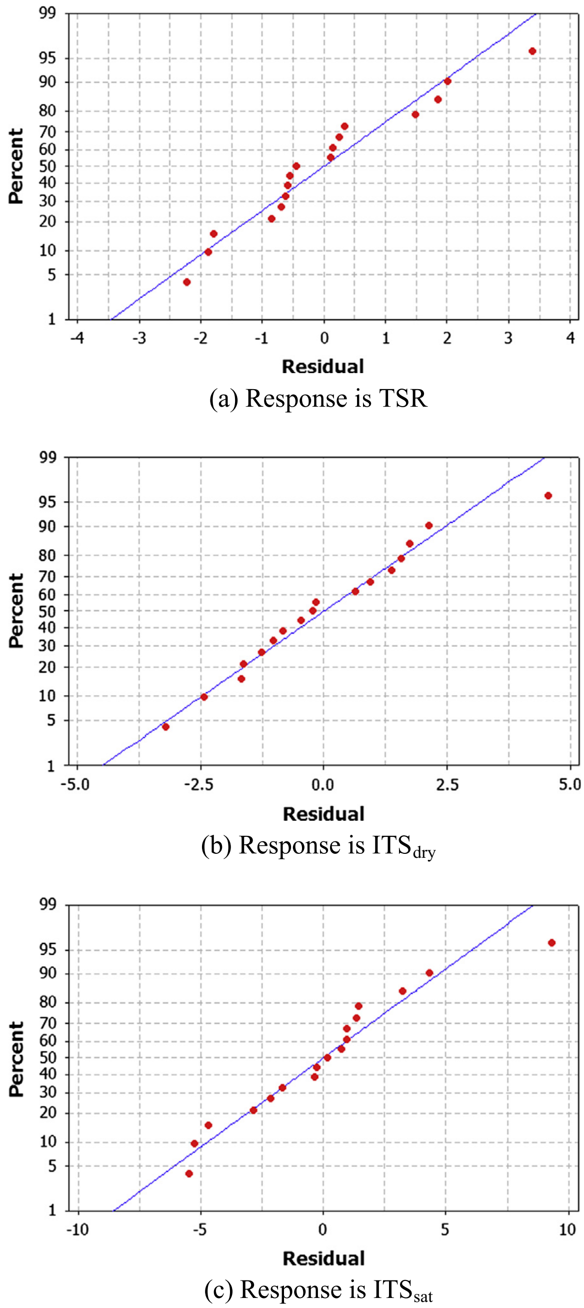


Fig. 5. Normal probability plots. (a) Response is TSR. (b) Response is ITS_{dry}. (c) Response is ITS_{sat}.

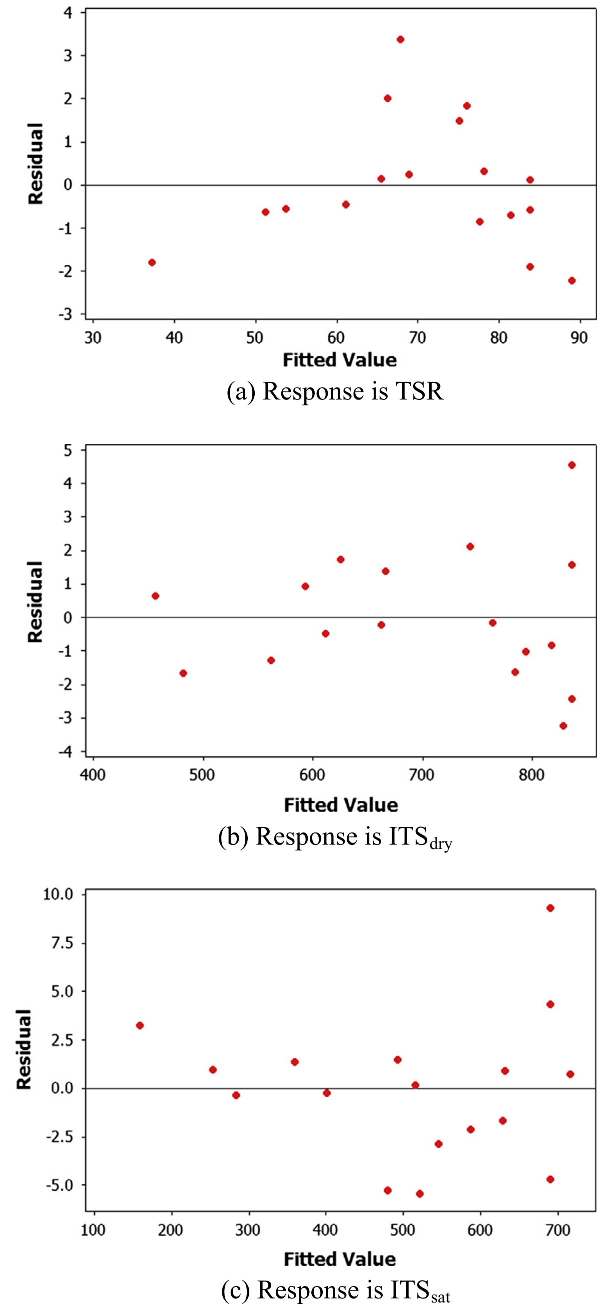


Fig. 6. Residual plots. (a) Response is TSR. (b) Response is ITS_{dry}. (c) Response is ITS_{sat}.

The maximum value of ITS_{dry} was 839.98 (kPa) obtained at LC = 1.5%, BC = 5.77% and PPSS 4.75 mm = 62.87% and the maximum value of ITS_{sat} was 715.95 (kPa) obtained at LC = 1.84%, BC = 5.75% and PPSS 4.75 mm = 70%.

7. Conclusion

From the statistical–experimental work and analysis in this study the following conclusions could be drawn:

- Analysis of the derived quadratic models showed that there were interactions between parameters and in some cases the second order terms had a pronounced effect on the responses. Therefore it may be generally concluded that in parametric studies, investigations should be directed so that any interaction and second order terms are also investigated.
- When each parameter (i.e. PPSS 4.75 mm, BC and LC) was increased from their low level to mid-level, lime content had the greatest effect on TSR increase, compared with the effects of BC and grading.
- The influence of PPSS 4.75 mm on decreasing TSR was much greater than the effects of LC and BC (when parameters changed from a mid-level to a high level value).
- LC–PPSS 4.75 mm and BC–PPSS 4.75 mm had interaction with each other in TSR as a response.
- In case of ITS_{dry}, LC–PPSS 4.75 mm and BC–LC had interaction with each other.

– BC–PPSS 4.75 mm had interaction with each other when ITS_{sat} is considered as a response.
– It was found that the maximum responses were achieved at around mid-levels of PPSS 4.75 mm, BC and LC.
– The models similar to those proposed here can be used for initial estimation of moisture susceptibility of asphalt mixture and their optimum design using minimum experimental works.

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