Chapter

Response Surface Methodology Optimization in Asphalt Mixtures: A Review

Aliyu Usman, Muslich Hartadi Sutanto, Madzlan Bin Napiah and Nura Shehu Aliyu Yaro

Abstract

The application of statistical modeling and optimization approaches such as response surface methodology (RSM) is important for the excellent potential to tackle different constraints and goals and the analysis of the relationships between independent factors influencing a particular response. This chapter provides a simple yet detailed literature review on the utilization of RSM for the design of experiments, modeling, and optimization of virgin and alternative materials into asphalt binder and mixtures for sustainability. Meanwhile, an in-depth analysis based on the literature reviewed in terms of asphalt binder modification employing RSM with various independent parameters were summarized. Also, a critical review of the application of RSM to optimize the engineering and mechanical performance characteristics of asphalt concrete mixtures is presented in this chapter. The current chapter concluded that the use of RSM statistical analysis in a highway materials perspective provides a broader understanding of the factors that control pavement performance throughout the pavement service life.

Keywords: asphalt binder, asphalt concrete mixture, response surface methodology, prediction, optimization

1. Introduction

In order to get the most benefits from a process and maximize its efficiency, optimization of the process is needed. Optimization refers to picking the ideal factor from a collection of potential solutions (independent variables). In certain applications, the value of the variable is enough to achieve the optimal output or best possible outcome. The common practice used to assess optimum design parameters is to evaluate the effect of each variable independently on the response [1, 2]. In this process, interactive effects among parameters are not regarded. Consequently, this approach does not display the full impact of these variables on the outcome. Another primary disadvantage of this method is the increase in the overall number of tests needed for the investigation, leading to an increase in costs and materials, and time [3, 4]. Owing to these drawbacks, researchers have been exploring alternative approaches. For the past decades, response surface methodology (RSM) is among the most effective approaches used for modeling and optimization. Myers, et al. [5] defined response surface methodology (RSM) as a statistical method that is commonly used to optimize engineering design and operations. The majority of RSM applications require multiple response variables. In a typical RSM analysis, the experimenter will create an empirical model like the second-order model to every response using these models to evaluate the configuration of the design variables that generate optimum or at least appropriate response values [2, 6]. RSM has great relevance in the design, development, and introduction of new material and the enhancement of material designs. RSM describes the influence of independent variables, either alone or in synergetic effect, during the process. It also helps in evaluating the influence of independent variables, this experimental approach produces a statistical model that explains the mechanism and processes [2, 5, 7]. While RSM has several benefits, it can be concluded that it applies to all modeling and optimization analyses of various aspect of engineering, RSM has now been commonly and successfully used to optimize asphalt binder and asphaltic concrete mixtures to maximize their performances and promote sustainability. The current research examined the application of RSM for modeling and optimization in asphalt pavement studies. In this chapter, several recently published RSM studies have been examined to have an overview and access the application of RSM in the pavement industry.

2. Design of experiment (DoE)

Design-Expert is a software for experimental design, statistical analysis, modeling, and optimization. It provides a variety of programs such as fractional factorial design, surface response, full factorial, mixing, and D-optimal designs [1, 2, 8]. RSM experimental designs are developed using the Design-Expert program. The program is also utilized to analyze the data obtained. Regression is applied to data obtained where the measured variable (response) is estimated based on a functional relationship between the predicted input variables. Experimental values that can be altered independently of one another are referred to as factors or independent variables [2, 9]. Variable levels are the various stages of the factors at which the experiments are to be performed. After conducting the experiment, the data obtained are called responses or dependent variables. While residual is the discrepancy between the experimental and predicted values for the determined range of experimental criteria also model with low residual values indicates a strong fitting of the experimental data [8, 9].

3. Response surface methodology (RSM)

Box and Wilson [10] introduced RSM in 1951 and they proposed using a second-degree polynomial model. RSM has recently been used for process parameter optimization. RSM can be considered as a systematic calculation technique for the optimization problem. This method provides an appropriate experimental method that incorporates all the independent variables and utilizes the experiment's input data to subsequently create a set of equations that can offer an output's theoretical value [11]. The findings are achieved from a well-designed regression analysis that examines the relationship between independent variables'-controlled values. Based on the new values of independent variables, the dependent variable can then be forecast [11]. RSM is an effective statistical tool for both the modeling and optimization of multiple variables with a minimum number of experiments to forecast the optimum performance parameters [7, 12]. By employing the RSM technique in the optimization process, the testing of all the variables relating to the product assessment requires just a short time, making the laboratory test stage more efficient [11].

Furthermore, the estimation of parameters that profoundly influence the model can determine which allows researchers to concentrate on those specific variables to improve the performance of the process [11]. In a set of experimental designs, one factor or process variable can depend strongly on or be dependent on another variable. In an attempt to discover the output–input relationship, understanding the interaction between the variables is critical, that is why taking a single factor at a time approach is seldom used to evaluate interrelationships between parameters. RSM can determine the relationship as well as interactions between the multiple parameters using quantitative data by creating a model equation. In RSM implementation, there are three steps; (i) experiment design, i.e., Box Behnken (BBD) and Central Composite Design (CCD); (ii) statistical and regression analysis to build model equations that describe the modeling of the response surface; and (iii) optimization of parameters/variables carried out via model Equation [13]. A statistical experimental design is presented in RSM. Different experimental designs could be carried out based on the special criteria and the choice of experimental points and numbers. In addition to randomizing the experimental error to every experimental point, operating with a statistical experimental design often implies the distributions of experimental points in the examined set of independent variables. These improve the reliability of the model Equation [5].

3.1 Central composite design (CCD)

The most widely and frequently employed and effective design technique is central composite design (CCD). A minimum of two numerical inputs is required and varied in the CCD approach at a range of alpha (α) over three (−1, 0, +1) or five (−α, −1, 0, +1, +α) stages. Three features are contained in the CCD model: (i) a complete factorial or fractional factor design; (ii) an additional design, mainly a star design with experimental points from the centre at alpha; and (iii) a central point. There are various ways to CCD depending on the alpha (α)-value, such as face-centred central composite (FCCD), rotational, spherical, orthogonal quadratic, and practical. Five levels are utilized for the rotational and spherical approaches depending on the number of variables. The value of alpha (a) for the FCCD is always unity. This means that the axial points are not positioned on the spheres, but rather on the centre of the faces, so only three variants of each parameter are involved [2]. **Figure 1**(**a** and **b**) illustrate the full factorial central composite model for two and three parameters optimization.

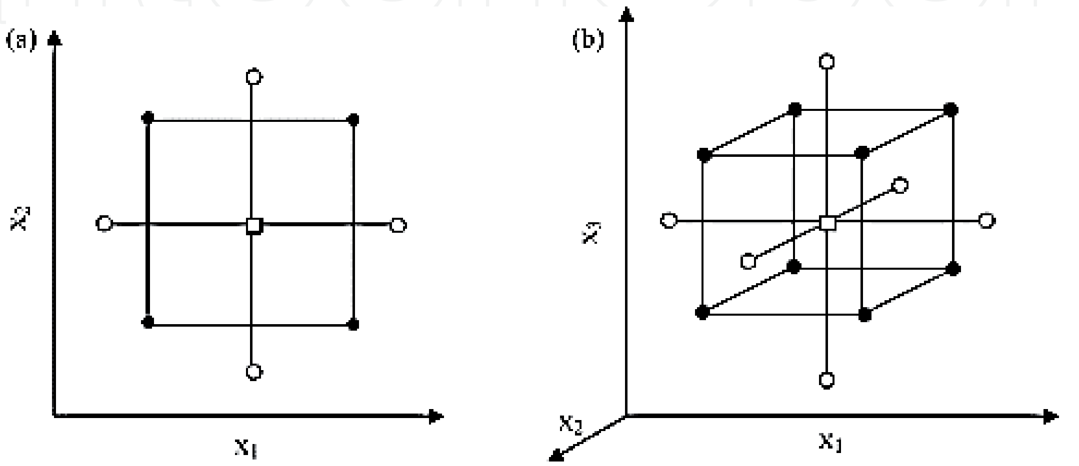

Figure 1.
Optimization of two and three parameters using CCD (a) two parameters (X_1 and X_2) where alpha (α) = 1.41 (b) three parameters (X_1, X_2, and X_3) where alpha (α) = 1.68 [12].

3.2 Box Behnken design (BBD)

Box–Behnken Design (BBD) suggested how to select points from a three-level parameter model to permit the first- and second-level coefficients of the statistical model to be effectively assessed. In this way, these designs, especially for many variables, are more efficient and cost-effective than their respective 3^k design models. A minimum of three numerical factors are required in BBD and vary across three levels. In Box–Behnken models, the experimental points are situated on a hypersphere spaced uniformly from the central point. BBD's key characteristics are: (1) it requires an experimental number depending on the Eq. $N = 2k(k-1) + cp$, where k is the number of variables and (cp) the number of central points; (2) it is appropriate to change all factor levels at three levels only (−1, 0, + 1) with intervals spaced equally. BBD has been used successfully as a physical and chemical technique for different optimization processes. Other RSM design techniques, such as one factor, optimal design, miscellaneous design, user-defined, and historical data designs, are available [2].

3.3 Motivation for the chapter

Due to the challenges facing the conventional pavement materials such as asphalt binder and mixtures and the paradigm shifts towards green and sustainable construction. The application of RSM is one of the promising ways used by pavements engineers as it has shown to be of great importance in the design, development, and incorporation of alternative green materials for the improvement of the pavement material design. Modeling and optimization of the synergetic impact of different parameters that affect the engineering properties and performance output of the asphalt binder and mixtures utilization help to provide more insight into the influences of the various variables. This experimental method generates a numerical method that helps elaborate on the mechanism and procedures that involve a lesser

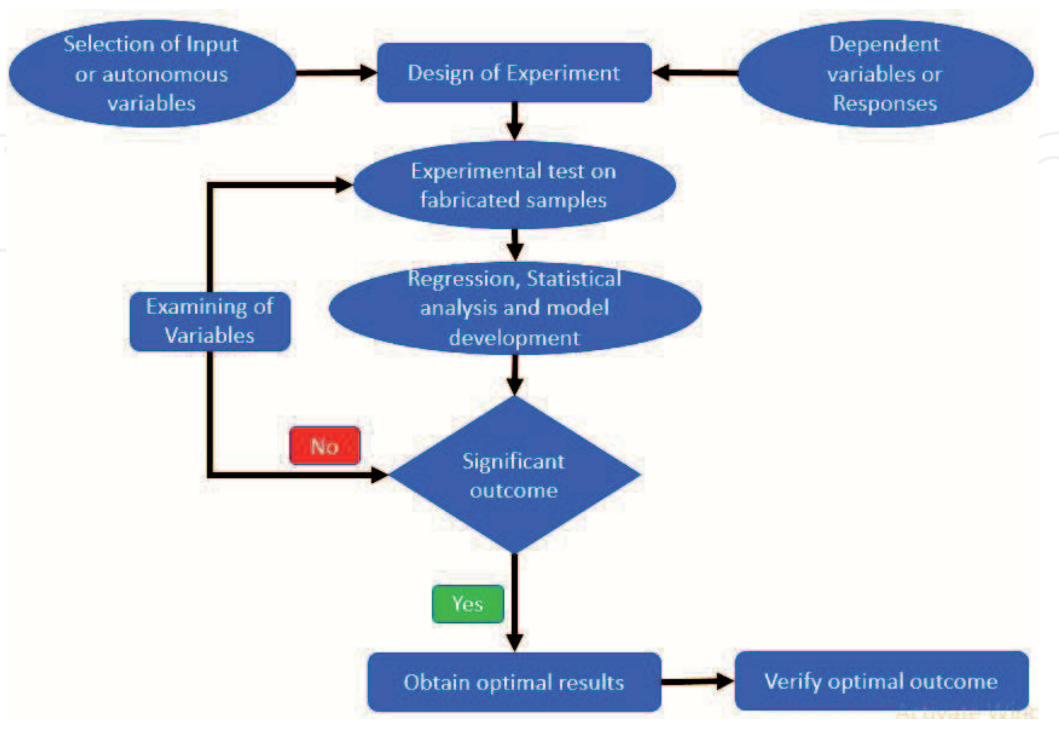

Figure 2.
General RSM design flow chart.

number of experimental runs. Thus, the utilization of RSM is of pivotal use for pavement engineers.

RSM is an effective instrument for engineering new bituminous blends. By forecasting the response of the materials on the basis of experimental plans drawn up with a scientific and statistical method [14]. Also, another RSM's key goal is to evaluate the optimal settings for control variables that lead to the maximum or minimum output over a certain area of study. The generated equations can be used for interpolation to obtain the maximum (or minimum) predictable results within the levels of the analyzed variables [14–16].

The general design flow chart of the RSM statistical technique framework is presented in **Figure 2**.

4. Asphalt mixing process for incorporating new materials

Three methods are employed to incorporate new sustainable materials into asphalt binders and mixtures for optimization. These methods are selected based on the type and properties of the new material to be incorporated. These methods are wet process, dry process, and modified dry process.

4.1 Wet process

The wet method comprises blending the newly added material with the heated asphalt binder to form the modified asphalt binder, The optimization is commonly done on the mixing parameters or the conventional properties of the mixes and the mixture is formed by blending hot aggregates with the modified asphalt binder. This method is suitable for materials having low melting points such as low-density polyethylene (LDPE), and polypropylene (PP). This method requires a high-shear mixer and sufficient time for blending the newly added material and asphalt binder [15].

4.2 Dry process

In the dry method, before adding asphalt binder to the mixture, the new sustainable green material is initially incorporated into the heated aggregates and mixed [16]. In this technique, some of the filler is lost as dust when blending the new material with the aggregates, which is not suitable [15]. This method is suitable for materials with a higher melting point above the asphalt mixture mixing temperatures such as polyethylene terephthalate (PET) and high-density polyethylene (HDPE). The optimization process using involves the mixing process and mechanical properties of the asphalt mixtures.

4.3 Modified dry process

In the modified dry method, new added sustainable green materials are incorporated while the heated asphalt binder and aggregates are thoroughly mixed [17]. The added new materials particles are ensured to be well coated by the asphalt binder. It is hypothesized that minor changes in the shape and properties of added waste materials during mixing will result from the modified dry process [15, 18]. Some experts modified the blending techniques to obtain a good distribution of the waste materials particles in the modified blends. The optimization process using involves the mixing process and mechanical properties of the asphalt mixtures.

5. Utilization of RSM optimization techniques in asphalt binder modification

RSM has been utilized in the modification of asphalt binder and optimization of the modification mixing parameters to enhance sustainability and improve performance of various bitumen modifiers using different dependent and independent variables associated with the bitumen, modification process, and performance of the bitumen. Assessment and investigation of the interactive effects on the response of process variables can thus be studied and analyzed using RSM. The model equation also quickly clarifies the effects with the various combination of the independent parameters. In this section the application of RSM for the modification of asphalt binder utilizing several types of alternative materials. Most of the prior study includes studies of the mixing conditions of asphalt binder and its conventional properties are discussed below.

A study conducted by Liu, et al. [19] evaluated the effects of mixing variables parameters such as mixing speed, time, temperature, and the modifier (diatomite and crumb rubber) on modified asphalt binder properties (penetration, softening point, penetration index, viscosity, elastic recovery, and ductility) were examined and optimization using RSM. The findings showed that with the increase in crumb rubber concentration, softening points, viscosity, elastic recovery, and penetration index increased, while penetration and ductility decreased. With the rise in diatomite concentration, the softening points, viscosity, and penetration index increase, while penetration and ductility decrease, which has little effect on elastic binder recovery. The shear temperature has had major impacts on penetration, ductility, softening point, and viscosity. Because of its similar mechanism of action, shear velocity, shear duration, and storage time have similar influences on binder properties. The optimum speed, time, and temperature of mixing were achieved at 55 min and 5300 rpm, 55 minutes, and 183 °C, respectively, based on the optimization. The effects of the various mixing parameters on the convention properties of the diatomite and crumb rubber modified bitumen is illustrated in the 3D surface plots in **Figures 3**-**5**.

Recently, the effects of various crumb rubber (CR) contents and their interactions with high-temperature ranges on the rheological activity of asphalt binder were also studied by Badri, et al. [20] At temperatures ranging from 46 °C to 82 °C, a temperature sweep test was performed using a dynamic shear rheometer (DSR) on modified binders with 5, 7, 10, 12 and 15% crumb rubber content. Based on central composite design (CCD) and considering the rheological parameters complex modulus (G^*) and phase angle (δ) as response variables, RSM statistical analysis was performed. The outcome of the ANOVA test showed that rheological parameters were significantly affected by temperature and rubber content with p less than 0.05. Independent effects of temperature and rubber content were analyzed, and the results showed that both responses were affected by the interaction of both independent variables but were more impacted by rubber content than temperature as depicted in the synergetic effect of the variables on the CR modified bitumen are shown in the 2D and 3D contour diagrams in **Figures 6** and **7**. It can therefore be inferred that RSM is an efficient tool for investigating rheological characteristics. For all responses, a percentage error of <5% was achieved, suggesting that the optimization process by RSM is a very efficient and effective technique.

Also, the RSM was used to evaluate both the volumetric and mechanical properties of asphalt mixtures after modifying the mix variables. A study conducted by Nassar, et al. [21] optimize the design mix variables, namely bitumen emulsion content (BEC), pre-wetting water content (PWC), and curing temperature (CT), the Response Surface Methodology (RSM) was used. The purpose of this work was

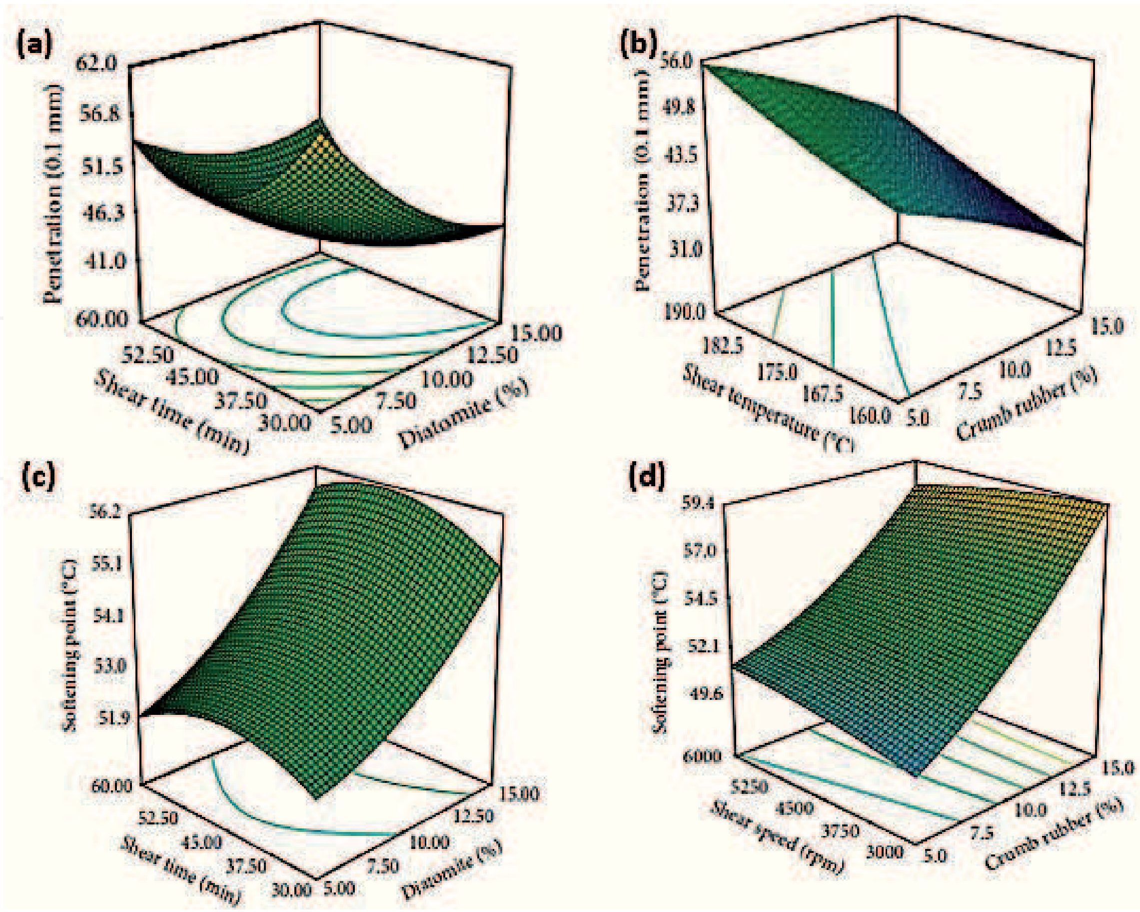

Figure 3.
Response surface plots for the preparation parameters on penetration values (a) shear time and diatomite (b) shear temperature and crumb rubber and for softening point. (c) shear time and diatomite content, (d) shear speed and crumb rubber content [19].

to evaluate the relationship influence on the mechanical and volumetric properties of cold bitumen emulsion (CBEMs) between these parameters. To determine the mechanical response, indirect tensile strength (ITS) and indirect tensile stiffness modulus (ITSM) tests were performed while air voids and dry density were calculated to obtain volumetric responses. Besides, the total fluid content was used in the typical mix design technique, the individual effects of BEC and PWC are significant. The findings show a lower CBEM strength/stiffness at the same overall fluid content and with varying ratios of BEC/PWC. The stiffness modulus assessment of the CBEM after 10 days is anticipated to provide the designer with sufficient information to optimize the CBEM mix model in a reasonable period. The overall 3D surface plots showing the interaction between the three autonomous factors on the output parameters.

Another research by Varanda, et al. [22] utilized RSM in the formulation of bitumen mixtures from the refining process of base oils utilizing asphaltic residue, vacuum residue, and three aromatic extracts (by-products). The asphaltic residue (A), vacuum residue (B), and the three different aromatic extracts (hereafter denoted by Extract-1 (C), Extract-2 (D) and Extract-3 (E)) from base oil refining, all derived from the same crude oil source (Arabian Light), To control bitumen formulation, a constrained mixture methodology was employed. The projected and calculated responses show that both models are reliable with average deviations of just 4.67% and 1.53% respectively for the penetration and the softening stage. Mixture design has been shown to be an effective and important instrument for bitumen formulation in general especially if a significant number of components are included in the blends. In general, in contrast to aromatic extracts, both asphaltic and vacuum residues impart greater stability to bitumen, which ensures that the

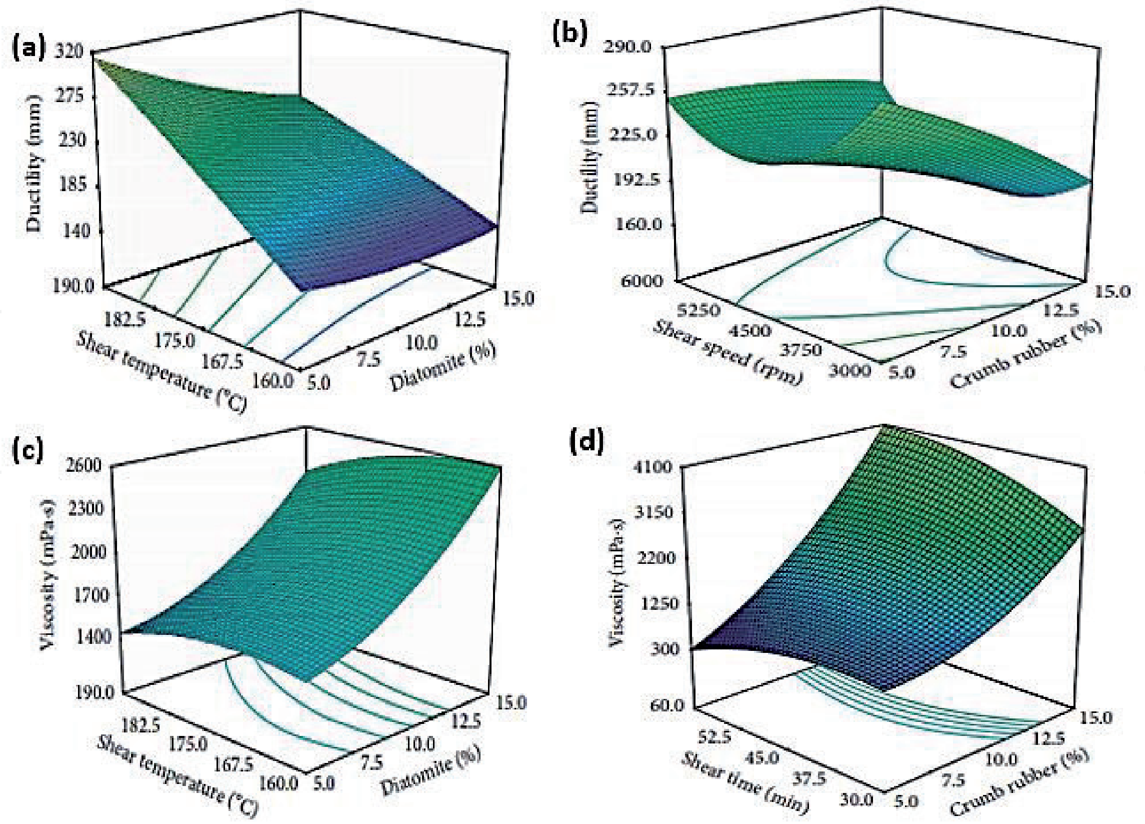

Figure 4.
Response surface plots for the preparation parameters on Ductility. (a) Shear time and diatomite (b) shear speed and Crumb rubber content and Viscosity values on (c) shear temperature and diatomite (d) shear time and crumb rubber [19].

softening point increases while penetration reduces. The asphaltic residue, however, transmits more difficult properties to bitumen n vacuum residue.

Wang and Fan [23] utilize Box–Behnken model RSM was to obtain the optimum values of process parameters for calcium sulphate whisker (CSW) modified bitumen. To access the mechanism of modification, three input variables, stirring time, stirring temperature, and production temperature was chosen. Three performances were evaluated as reactions by testing in the, including high-temperature efficiency, low-temperature efficiency, and deformation resistance related to the bitumen properties. The study found that mixing time of 32 min, mixing temperature of 175 °C, and production temperature of 175 °C were the optimum process parameters within the range of this analysis, with accurate precision compared to actual experimental results. In contrast, the influence of three process parameters on bitumen properties was also investigated, and stirring time was found to have a more important impact on the softening point, penetration, and ductility. CSW has a reasonable dispersion in the bitumen matrix under the optimization process parameters and has been shown to increase the physical performance of the bitumen.

del Barco Carrión, et al. [14] use RSM to develop a modified bitumen with a mixture of Liquid Rubber (LR), a uniform mix of 50–70% pre-processed Recycled Tyre Rubber (RTR) in conjunction with wax and heavy oils blend. To forecast the response of different combinations of LR and Ethylene Bis Stearamide (EBS) in terms of temperature (high and low) properties and expenses, the RSM was used to optimize both conventional and rheological properties of Polymer Modified Bitumen (PMBs) commonly utilized in bitumen blends and roofing membranes. Both two modifiers show improve bitumen elasticity and stiffness, thus complementing each other. In general, the LR oils decrease the stiffness of the neat bitumen whereas the EBS has been shown to increase the stiffness and elasticity of

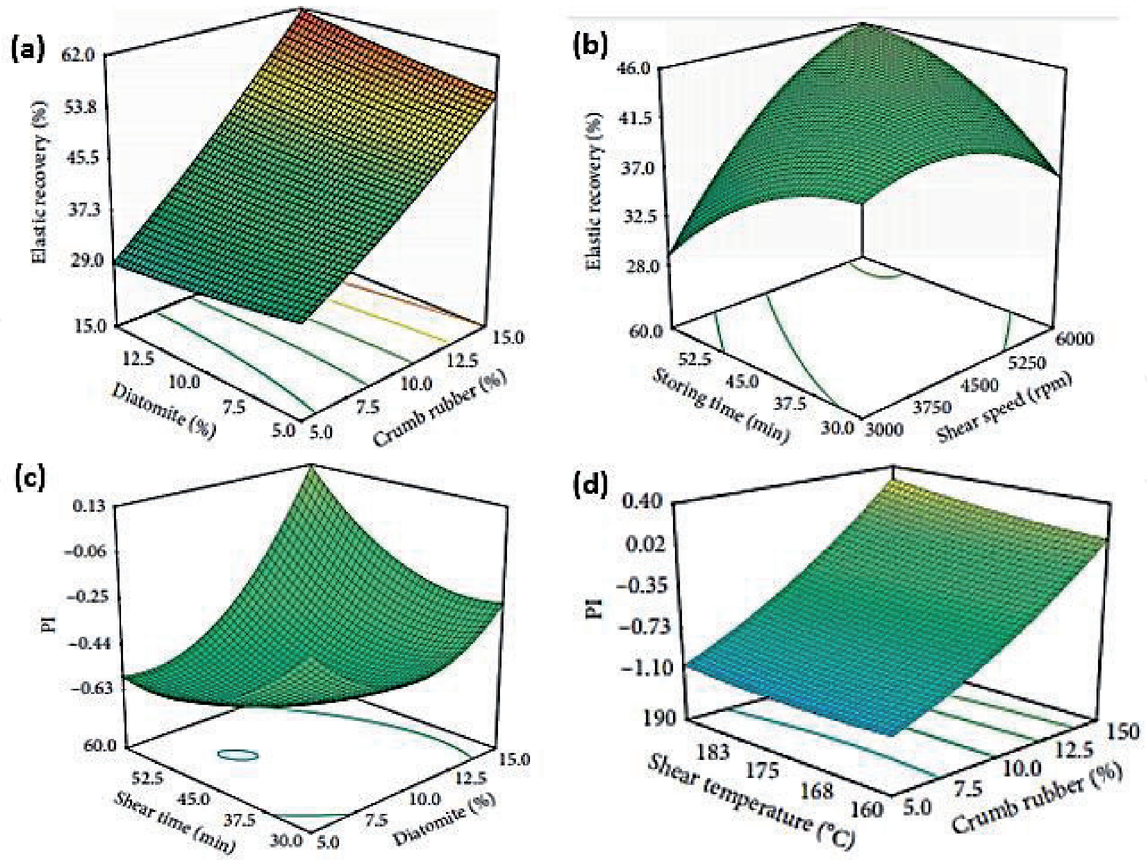

Figure 5.
Response surface plots for the preparation parameters on Elastic recovery. (a) Diatomite and crumb rubber (b) storing time and shearing speed and PI values of (c) Shearing time and diatomite content (d) shear temperature and crumb rubber content [19].

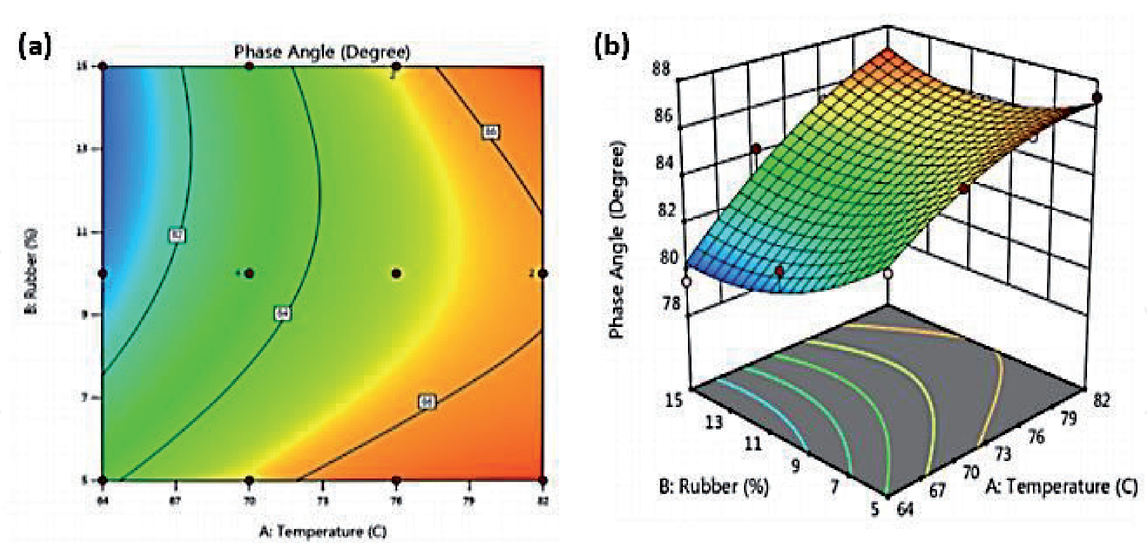

Figure 6.
Effects of input factors on phase angle (a) 2D contour for the synergistic influence of rubber content and temperature (b) 3D surface diagram for the synergistic influence of rubber content and temperature.

the blends significantly, thus enabling the use of higher LR quality to comply with disadvantages. LR contents in the range of 30–40% by weight of neat bitumen are the optimum composition of blends, thus reducing the need for virgin bitumen in terms of overall modification for both pavement and roofing.

Recently, Memon, et al. [24] utilizes RSM for modeling and optimizing the bitumen physical characterization, the mixing conditions of petroleum sludge modified bitumen (PSMB) using the penetration, softening point, penetration index, and

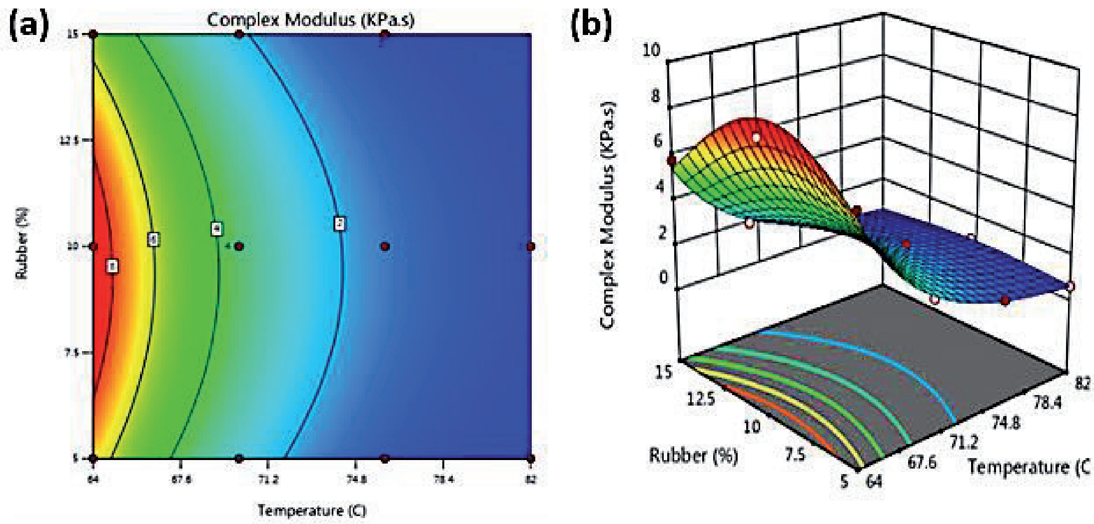

Figure 7.
Simultaneous effect of input parameters on complex modulus (a) Plot of 2D contour on the synergistic influence of rubber content and temperature (b) 3D plot for the synergistic influence of rubber content and temperature.

Authors	Autonomous factors	Responses
Bala, et al. [25]	Nanosilica content, and temperature	Complex modulus, Phase angle, Complex viscosity
Phan, et al. [26]	Hydrated lime content and asphalt binder concentration	Bitumen Linear viscoelastic properties and Fatigue resistance
Bala, et al. [25]	LDPE and binder content	Complex modulus, Phase angle, and Viscosity
Chen, et al. [27]	Test temperature, polystyrene dosage, and polystyrene molecular weight	G*/sin (δ) for unaged blends, G*/sin (δ) for short-term aged blends, and stiffness, m-value
Varanda, et al. [22]	Aromatic extracts vacuum residue and asphalt residue	Softening point and penetration,
Al-Sabaeei, et al. [28]	Crude palm oil (CPO) and temperature	Complex modulus (kPa), and phase angle (δ) for both aged and unaged bitumen
Jamshidi, et al. [29]	Solution temperature, sasobit, and test temperature	Unaged viscosity, STA viscosity, LTA viscosity
Mohammed, et al. [30]	Bitumen and rice husk warm mix asphalt	Penetration and softening point
Yıldırım, et al. [31]	Number of blows, temperature, additive rate, and bitumen content	Optimum bitumen content (OBC)
Khairuddin, et al. [32]	Polyurethane (PU) and bitumen	Penetration, softening point, and viscosity
Solatifar, et al. [33]	Mixing temperature, mixing time, mixing speed, and crumb rubber content percentage	Rutting parameter.

Table 1.
Summary of previous works of literature on the utilization of RSM for asphalt binder optimization.

storage stability. The findings show that the stiffness of PSMB was strengthened by the synergistic effects of mixing temperature and speed, whereas the mixing time initially reduces and then increases the stiffness of PSMB. The PSMB met the storage stability and the penetration index requirements for bitumen modification under optimum mixing conditions. This enhancement in stiffness at higher mixing conditions is due to the increased ratio of maltenes to asphaltenes in PSMB. While at high mixing conditions, the softening point influences were reduced, whereas it was noted that the lightweight oil component of the PS was also responsible for the softening point decline of the PSMB. The mixing time, speed, and temperature for PSMB were evaluated to be 53 min, 1292 rpm, and 149 °C, respectively, based on the RSM optimization. The overview of prior works on the optimization of various autonomous parameters on bitumen conventional properties is displayed in **Table 1**.

6. Application of RSM in modeling and optimization of materials for asphalt mixtures modification

Several RSM studies have been published, this study emphasizes the utilization of RSM for optimizing virgin or waste materials as alternative asphaltic mixtures materials for sustainability. In this section, the application of RSM for the optimization of the virgin as well as waste secondary materials will be discussed depending on the work of existing literature.

The application of Response Surface Methodology (RSM) for the prediction of Marshal volumetric properties is being explored by Bala, et al. [34] Polyethylene and nanosilica were used as the independent factors in the analysis, while the air

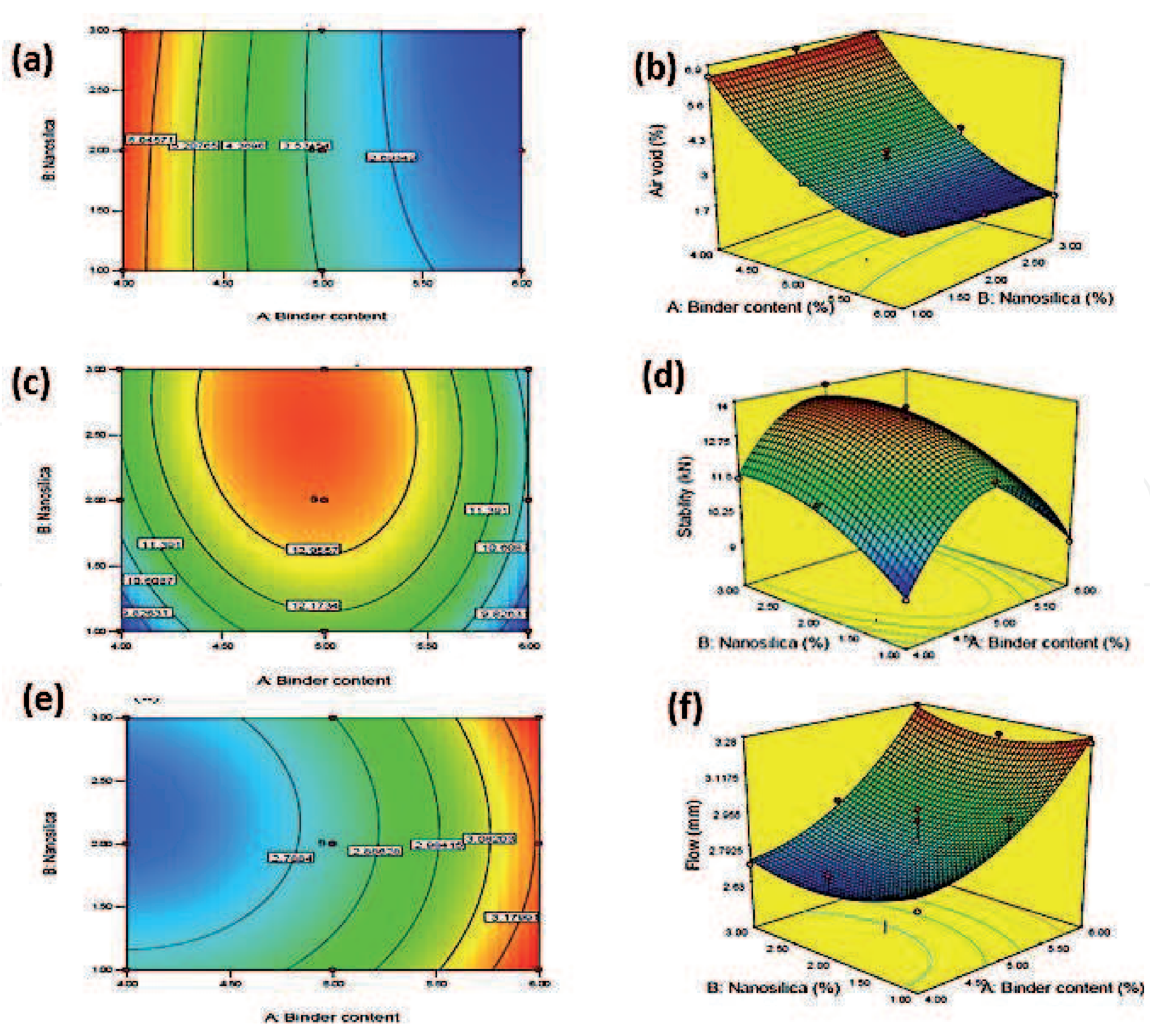

Figure 8.
2D and 3D RSM contour plots for the optimization of nanosilica and binder content (a-b) Air void (c-d) Stability (e-f) Flow [34].

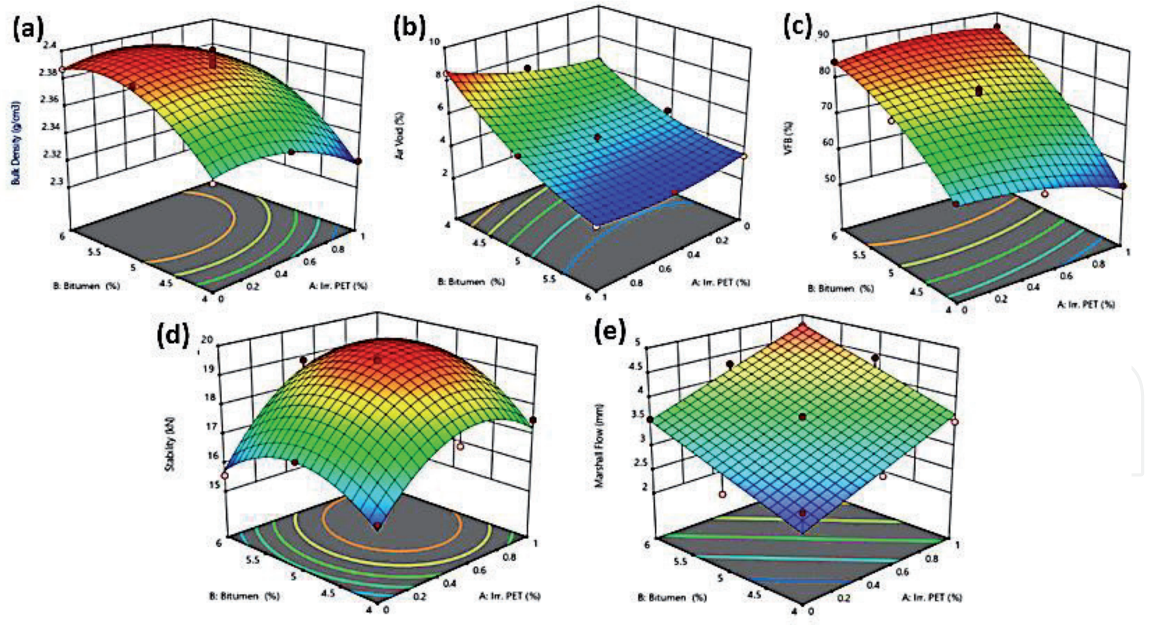

Figure 9.
RSM 3D contour for the optimization of irradiated PET fiber and binder content (a) Density (b) Air void (c) VFB (d) Stability (e) Marshall flow [35].

void, flow, and Marshall stability were the responses. Findings show that RSM-based statistical analysis confirms that it is possible to use a quadratic model built with a high degree of correlation and predictive capacity to predict the Marshal volumetric properties of the mixture. **Figure 8(a)** and **(b)** demonstrates that the binder content has more impact on the air void than the nanosilica content, whereas **Figure 8(c)** and **(d)** illustrates that both independent factors have an influential effect on the Marshall stability of the asphalt mixture. On the Marshall flow values for the nanosilica modified asphalt blend, a combined effect of both variables was noted but the binder content has a more pronounced impact on the flow values as presented in **Figure 8(e)** and **(f)**.

Recently, Usman, et al. [35] optimize irradiated waste PET fiber and binder contents utilizing RSM on the volumetric and strength properties of fiber-reinforced asphalt mixes. **Figure 9(a-e)** illustrates the interactive impacts of the mixture design parameters on the dependent variables. It was hinted that both independent factors have a significant positive effect on the bulk specific density (BSD), Marshall stability, and the Marshall flow values for the fiber-reinforced asphalt mixes. However, on the air void (AV) and voids filled with bitumen (VFB), the asphalt binder content has a more pronounced influence compared to the irradiated waste PET fiber content. The investigation concluded that the use of fibers in asphalt mixture production improves the strength and performance characteristics of asphalt mixes and based on multi-objective optimization analysis, 5.25% and 0.53% as the optimized contents for binder and irradiated waste PET, respectively.

Likewise, in 2020, Omranian, et al. [36] investigate the effects of short-term aging on asphalt concrete mixture compactibility and volumetric characteristics. Three independent parameters, including aging temperature, aging period, and duration in humidity and ultraviolent chambers, were considered in this analysis, while the compaction energy index (CEI) and volumetric characteristics, were considered as responses. Significant impacts of aging temperature and duration on compactibility, air voids (AV), mineral aggregate voids (WMA), and asphalt filled voids (WFA) are revealed in the research findings. However, duration in the environment chamber did not exhibit any significant effect on responses, as shown in **Figure 10(a-d)**. Finally, the analysis shows the ability of the RSM to predict

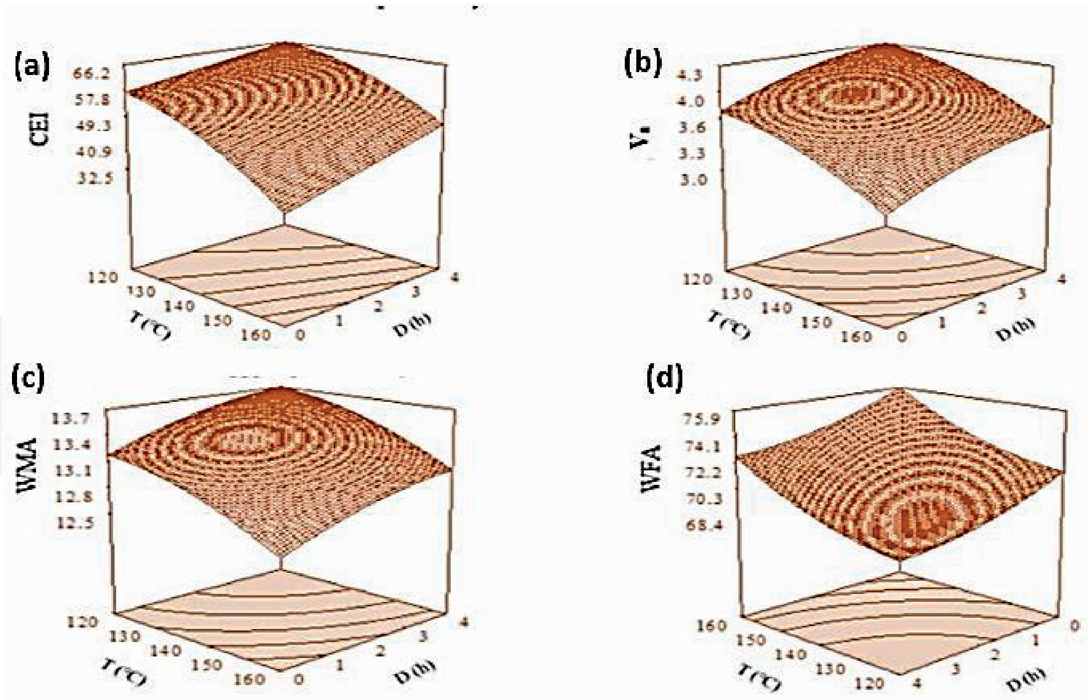

Figure 10.
Graphical representation of RSM 3D contour (a) CEI (b) Va (c) VMA (d) WFA [36].

changes from mathematical equation responses that correlate with the empirical findings with good precision. This finding concluded that to achieve the desired requirements, pavement designers should use RSM statistical technique to predict the pavement density and adjust pressure as well as the number of rolling passes.

Khan, et al. [37] explore the applicability of utilizing RSM to investigate the relationship between autonomous and dependent parameters for the formulation of cementitious grout. In the study, regular and irradiated waste PET and fly ash contents were optimized. A high coefficient of determination (R^2) with an adequate precision (AP) of greater than 4 from the analysis of variance was reported. It was further revealed that gamma irradiation exposure of waste PET resulted in the usage of a higher percentage of the waste PET in comparison to the regular waste PET without compromising the properties considered in the study. Moreover, the investigation concluded that waste PET treatment with gamma rays could be an innovative and effective way to recycle waste PET in the formulation of cementitious grout for semi-flexible pavement application as cement replacement material and can be an important advancement to attaining the zero-waste plastic goal of the united nation sustainable development.

The permanent deformation property of asphalt concrete incorporating various concentrations of recycled asphalt pavement (RAP) and quantities of the waste engine and cooking oil was evaluated by Taherkhani and Noorian [38] using response surface methodology. The study substituted 25, 50, and 75% of total aggregates with RAP and rejuvenated each with 5, 10, and 15 percent (by total binder weight) of waste engine oil (WEO) and waste cooking oil (waste cooking oil) (WCO). A polynomial quadratic model was reported to be accurate to predict the permanent strain employing RSM in the Design-Expert software. RAP and oil content, squared oil content, and oil types were significant terms for the prediction of permanent strain. Results show that with increasing RAP content, permanent strain decreases, but for each RAP content, the lowest permanent strain is reached at a specific oil content amount. The finding concluded that through RSM optimization, the concentration of oils was obtained to achieve asphalt mixture with a comparable control mix deformation property.

Authors	Autonomous factors	Responses
Hamzah, et al. [49]	Mixing temperature and test temperature	Direct tensile strength (DTS), adhesion, broken aggregate, and fracture energy
Bala, et al. [50]	Polyethylene, polypropylene, and nanosilica	Fatigue life
Usman, et al. [51]	PET fiber and temperature	Resilient modulus
Moghaddam, et al. [52]	PET and binder contents	VIM, VMA, BSG, stability, and flow
Yıldırım and Karacasu [53]	Temperature, waste rubber content, glass fiber content, and bitumen content	PSG, voids, VFA, Marshall stability
Soltani, et al. [54]	PET, stress level, and temperature	Fatigue cycles
Moghaddam, et al. [55]	PET, stress level, and temperature	Stiffness
Haghshenas, et al. [56]	Grading, bitumen content, and lime content	Indirect tensile strength (dry and saturated), TSR
Khodaii, et al. [57]	Grading and lime content	Indirect tensile strength (dry and saturated), TSR
Hamzah, et al. [58]	Compaction temperature, binder content, and recycled asphalt content	VFA, air void, G_{mb}, resilient modulus, stability, and flow
Nassar, et al. [21]	Curing time, Pre-wetting water and Bitumen emulsion content	Air void, indirect tensile, strength (wet and dry), and indirect tensile stiffness modulus
Golchin and Mansourian [59]	RAP content, asphalt binder type, and Loading strain	50% of initial stiffness, fatigue life (Number of cycles), and final stiffness
Santos, et al. [60]	Temperature, plastic percentage, and size of particles	Bulk Specific Gravity

Table 2.
Summary of previous works of literature on the utilization of RSM for asphalt mixtures optimization.

Bala, et al. [39] employed RSM to optimize two independent parameters, namely nanosilica and binder content effects on the response factors VMA, Marshall stability, flow, fatigue life, and indirect tensile strength (ITS). It was observed that VMA decreases substantially for binder content from 4–5%, beyond that it experiences a decreasing trend for mixtures fabricated with binder content between 5–6%. The findings also reported that nanosilica content has less influence on the VMA compared to the binder content. Also, the contour plot revealed that on the Marshall stability, the nanosilica particles have a marginal effect than the binder content. For the flow, fatigue life, and ITS, both nanosilica and binder contents have significant impacts on the nanocomposite modified asphalt mixes. The finding concluded that 2.67% and 4.65% as the optimized nanosilica and binder contents for an improved mixture performance property.

Several studies have been performed on the effect of different alternative materials on asphalt concrete mixtures [19, 40–48]. **Table 2** presents the summary of some selected work done utilizing RSM for different independent factors on several mechanical performance properties of asphalt concrete mixes.

7. Conclusions

RSM has effectively been utilized for various applications in the pavement industry. The current book chapter provides an overview of RSM applications for bitumen, asphaltic mixture modification, and performance properties. From the review, it was observed that RSM has many benefits in improving the knowledge about the synergetic effect of various modification variables on the bitumen performance. RSM technique provides an in-depth understanding of the influence of other responses with the variability each mix design factor would have on the asphalt mixture performance. RSM also has shown the benefit of analyzing various autonomous variables concurrently. For several optimization research, the implementation of RSM to achieve optimum dependent variable outcome leads to considerably reduced costs of running experiments while at the same time optimizing the performance properties of both the bitumen and asphaltic mixtures. Thus, with the need to optimized mix design, RSM plays a crucial role in the pavement industry to establish a performance-based mix design about the above criteria. Generally, RSM can also be regarded as an effective alternative to optimize and understand the pavement mix design parameters effectively to produce optimal mixtures with less cost and sample runs. It was shown in this chapter that the RSM exhibits the great ability to determine the compactness and mechanical efficiency properties of asphalt binder and mixtures under different conditions quickly and accurately. With appropriate precision, the model developed by the RSM always fits into the experimental observations. This means that in predicting the effects of the autonomous parameters on the response variables, these models are accurate and realistic. RSM's proposed models can be used by the highway industry as a valuable and effective way to controlling and preparing the construction method to achieve the best pavement performance characteristics, which can significantly increase pavement performance and longevity.

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Conflict of interest

The authors declare no conflict of interest.

Author details

Aliyu Usman*, Muslich Hartadi Sutanto, Madzlan Bin Napiah
and Nura Shehu Aliyu Yaro
Department of Civil and Environmental Engineering, Universiti Teknologi
PETRONAS, Bandar Seri-Iskandar, Malaysia

*Address all correspondence to: aliyu_17005209@utp.edu.my

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