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Rebound resilience of natural rubber composites via response surface methodology

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ABSTRACT –A statistical model was developed in this study to describe rebound resilience of natural rubber composites which was prepared by using a Haake internal mixer. Response surface methodology (RSM) based on central composite centered design (CCD) was employed to statistically evaluate and optimize the conditions for maximum rebound resilience and study the significance and interaction of black filler and glycerol on rebound resilience yield. With the use of the developed quadratic model equation, a maximum rebound resilience 71° was obtained to be a black filler loading of 50 phr and glycerol loading of 7 %.

1. INTRODUCTION

Natural rubber (NR) was extensively used in many applications due to its high elasticity (reversible deformability). However, the rebound resilience of neat NR are low. For a number of application, addition of a reinforcing was necessary [1-3,8]. Experimental work to optimise the formulation can be designed using suitable mathematical and statistical tools such as design of experiments (DOE). Some researcher claim that it is possible to obtain quantitative relations for the effects of multi process parameters on the properties of the NR composites via RSM at a minimum number of experiments [4-5]. In this present study, RSM was used to develop a mathematical correlation between formulations to produce NR composites with a smaller sample size [5].

2. METHODOLOGY

NR composites were prepared based on 100 phr of Natural Rubber (NR) SMR-20. Curing additives for all formulations based on 100 parts of rubber were: 1.5 phr of sulphur (S), 5 phr of Zinc oxide (ZnO), 2 phr of stearic acid, 0.3 phr of Tetramethyl Thiuram Disulphate (TMTD) and 2 phr of 6PPD. The rubber compound was prepared using a Haake internal mixer working at 60°C and a rotor speed of 60 rpm for 7 minutes according to ASTM D-3182. The rubber compounds were subsequently compression molded at 150°C using a hot press based on the respective cure time, t_{90} which is in accordance with ASTM D 2084.

RSM was used to optimize rebound resilience of NR composites. The central composite centered design (CCD) was applied to study process variables. The experimental runs were carried out according to a 2^2 full factorial design for the two identified design independent variables, namely, black filler (X_1) and glycerol (X_2) with low (−1) and high (+1) levels. Thirteen sets of experiments were carried out in this study with four star points and five replications at the centre points. The levels of variables chosen for this trial are given in Table 1. Response selected was rebound resilience. The levels were selected based on preliminary study results. The model used in this study to estimate the response surface is the quadratic polynomial represented by the following Equation (1):

$$Y = \beta_\circ + \beta_1 X_1 + \beta_2 X_2 + \beta_{11} {X_1}^2 + \beta_{22} {X_2}^2 + \beta_{12} X_1 X_2 \quad (1)$$

Table 1 The level of variables.

Black filler (X_1, phr)	**Glycerol (X_2, %)**
50 (-1)	5.0 (-1)
75 (0)	6.0 (0)
100 (-1)	7.0 (+1)

Rebound resilience were maximized according to BS 903 PT A8 standard and tested using the DUNLOP Tripsometer at room temperature.

3. RESULTS AND DISCUSSION

3.1 Optimisation factor using full factorial CCD

According to the response surface plot, the maximized rebound resilience of NR composites were obtained at black filler loading of 50 phr and glycerol loading of 7% which is 71° (Figure 1). This case is supported by a perturbation plot as at Figure 2 where the black filler (X_1) loading has a greater effect than the glycerol (X_2) loading as it changes from the reference point. However, the black filler loading shows a negative effect on the process because it exhibits a downward plot, whereas the glycerol loading shows a positive effect as the line takes slightly downward plot. Many authors reported that the rebound resilience decreased with an increased the filler loading [1,6-8]. This is simply attributed to the dilution effect, because it is known that the rubber portion provides an elastic response as measured in terms of the rebound resilience [8-9]. The desirability function is linear with the value of 1 [10], as depicted in the Figure 3. The regression equation characterizing the influence of different considered variables on process yield was obtained on Equation (2):

$$Y = 59.01 - 11.39X_1 - 0.11X_2 + 0.24X_1{}^2 - 0.75X_2{}^2 + 1.0X_1X_2 \quad (2)$$

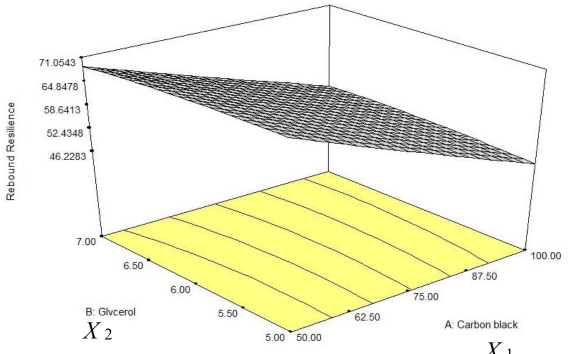

Figure 1 Effect of the black filler (X_1) loading and glycerol (X_2) loading on the resilience of the NR composites.

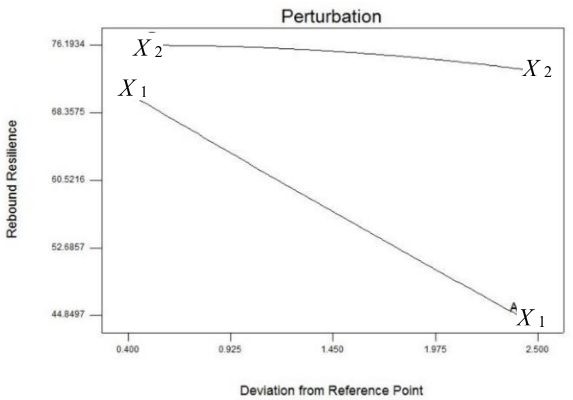

Figure 2 Perturbation of factors X_1 and factor X_2 at the reference point.

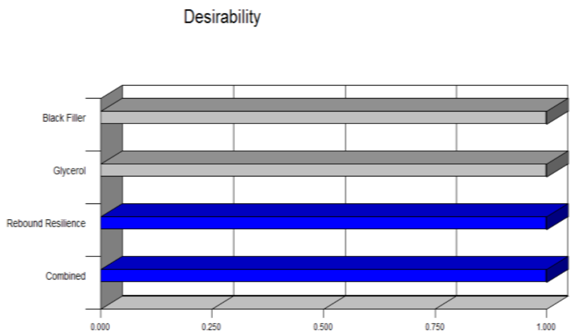

Figure 3 Effect of the independent variables, response, and combination for optimization desirability.

4. CONCLUSION

RSM and CCD proved to be reliable and powerful tool for modelling, optimizing and studying the interactive effects of two process variables. The maximum predicted and actual rebound resilience yields were 71.01° and 71°, respectively. The final combination of factors used to achieve this rebound resilience is at black filler of 50phr and glycerol of 7%.

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