Physical properties of black filled natural rubber composites via response surface methodology

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ABSTRACT – Performance of an elastomeric mount is highly depending on the manufacturing processing parameters. In this study, the effect of curing parameters using a hot press machine on physical properties of commercialized black filled natural rubber composites was investigated. All the hot press machine parameters (temperature, pressure and curing time) called independent variables were optimized to maximizing the responses (swelling percentage and density) using response surface methodology (RSM) via two-level full factorial design. The selected model was accurate to analyze the interaction between the parameters with the coefficient of determination approaching unity of more than 0.9993 for both responses.

1. INTRODUCTION

Engine mount is one of the important compartments in any vehicles. Engine mount helps to reduce noise, vibration and harshness (NVH) to gives the best comfort for passengers and drivers. Also, it helps to support the weight of the engine and distributes the load uniformly to chassis.

Passive engine mount consists of elastomeric and hydraulic types. Since 1930s, passive engine mount has been used widely and the elastomeric is the first generation of engine mount [1].
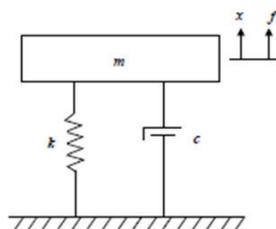

Figure 1 Voigt Model [2]

The passive engine mount is one of the toughest among others and also has simple designs, compact, cost effective, free from maintenance as well as durable. The mechanical of the passive engine mount can be shown as Voigt model (Figure 1) which consist of spring and viscous damping [2] only. It shows that the engine mount is place under vertical load at the same time and bolted freely with the engine and chassis.

Natural rubber (NR) composites is a versatile polymer and have outstanding performances such as high strength and resilience, also efficient bonding with metal and reinforcing materials [3]. It is reported to been extensively used in static and dynamic applications due to its high elasticity and toughness [4]. Therefore, it is chosen for noise and vibration isolation in rubber engine mount.

Optimization of processing parameters is strongly needed to produce high quality of dry rubber components. Optimized parameters help to reduce the cost on rejected product and proven to be cost effective [5]. Therefore, this study focusing on the screening methodology using widespread used Response Surface Methodology (RSM) for the optimization of hot press processing parameter; A: temperature (140 - 180°C), B: pressure (100 – 140 kg/cm²) and C: curing time (5 – 15 min).

2. METHODOLOGY

2.1 Natural Rubber Compound

Natural rubber compound, commercial grade NR60 supplied by HML Auto Industries (M) Sdn Bhd. This compound is technically specified for high-performance engine mountings, tires, conveyer belts and mostly in general rubber products.

2.2 Designing the Processing Parameters using Response Surface Methodology (RSM)

Design of experiment was carried out using Design Expert Software (Statistics Made Easy, version 6.0.8 Portable). Two-level factorial design experiment was utilized in this study. There were 11 experiments with 3 replications at center point. Table 1 shows the level of variables in this study.

Table 1 Level of Variable

Temperature (A; °C)	Pressure (B; kg/cm2)	Curing time (C; min)
140 (-1)	100 (-1)	5 (-1)
160 (0)	120 (0)	10 (0)
180 (+1)	140 (+1)	15 (+1)

2.3 Fabrication using Hot Press Machine

The NR60 compound continuous sheet was cut into smaller pieces and was carefully filled into a mold cavity to undergo the simultaneous fabrication and curing process. It was compressed using a GT7014-A

hot press machine with the combination of parameter ranges (temperature, pressure and time) set by the software. The thickness of the mold used was 1 mm.

2.4 Physical Testing

The NR60 vulcanized sheets of 1 mm thick were cut into 10 x 10 mm and immersed into toluene for 72 hours at ambient temperature (25°C) in accordance to ASTM D 471. The samples were weighed before and after the immersion. The swelling percentage calculated using Equation 1 where M_i was the initial mass and M_s was the mass of the specimens after immersion in gram.

$$\text{Swelling percentage} = \left[\frac{(M_s - M_i)}{M_i}\right] \times 100 \tag{1}$$

Meanwhile, density of the vulcanized NR60 composites measured according to ASTM 1895 by using an Electronic Densimeter MD-300S (AlfaMirage, Japan). At least three measurements taken for each sample to get the average value.

3. RESULTS

3.1 Regression Models and R2 Values of Factor Interaction

The regression models of density, Y1 and swelling percentage, Y2 for the factors interaction the R-squared, R2 and adjusted R-squared, Adj. R2 values are tabulated in Table 2. The R2 values indicate the degree of agreement between the experimental results with those predicted by model. R2 values for all responses are obtained in range of 0.90 – 0.99 which are very close to union (R2 = 1) [4-5]. The model presented almost 100% of the variation in the overall system indicating accuracy in describing and predicting the pattern of significance.

Table 2 Regression models

No	Response, Y	R2	Adj. R2
Density	$Y_1 = 1.18 - 0.051A - 0.020B - 0.022C + 0.011AB + 0.024AC + 0.023BC - 0.039 ABC$	0.9994	0.9971
% Swelling	$Y_2 = 124.93 + 0.36A + 3.83B - 12.75C + 10.27AB -7.41AC + 4.5CB + 9.60ABC$	0.9993	0.9967

3.2 Interaction between Variables for Physical Properties

The effect of all parameters on swelling percentage and density of the NR60 composites represented by perturbation plots in Figure 2. The most critical parameter [5] on swelling was curing time. As the time increased, the swelling percentage decreased attributed to the increased in cross-linked density, causing low penetration of solvents. While the biggest contributor for density was temperature. As the temperature increased, the density of the NR60 composites decreased. This is due to the degradation experienced by the rubber chains at high temperature.

4. CONCLUSIONS

A systematic investigation on the effect of processing parameters on physical properties of NR60 composites was successfully conducted using Design Expert Software via the RSM. The optimized hot press parameters to achieve low swelling percentage of 107.692 % and appreciable density of 1.219 g/cm^3 are at temperature of 140°C, pressure of 140 kg/cm^2 for the curing duration of 15 minutes. The finding is beneficial for the improvement of physical as well as mechanical properties of dry rubber product utilizing NR60 compound.
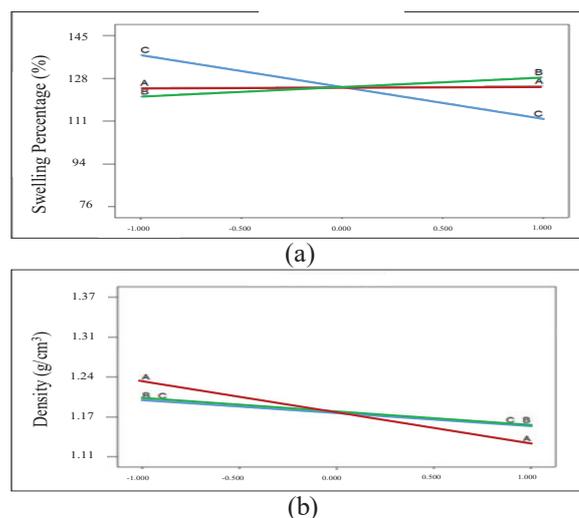

(a)

(b)

Figure 2 Pertubation Plots of Swelling and Density

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