Development of tyre tread compounds for good wet-grip: effects of rubber type

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Abstract. The present work reported the study of the effects of type of rubber on energy loss of tyre tread compounds for radial tyres which determines wet-grip properties of the tyres derived from them. The types of rubbers studied were solution SBR (S-SBR), emulsion SBR (E-SBR), functionalized S-SBR (FS-SBR), natural rubber (NR), functionalized NR (CNR), butadiene rubber (BR) and their selected blends. The wet-grip property was assessed by measuring tan δ at 0°C. It was found that FS-SBR gave tread compound with the best wet-grip property followed by S-SBR, CNR, E-SBR, NR and BR. Blends of SBR with lower ranking rubbers (CNR, NR and BR) also gave lower values of tan δ at 0°C or poorer wet-grip properties. The results can be explained by the viscoelastic properties of the rubbers and their interactions with silica.

1. Introduction
The trend in development of tyres are towards low rolling-resistance, good wet-grip and low noise tyres. The present research was undertaken with the objective to obtain knowledge and technologies for production of energy-saving, good wet-grip and low noise tyres and disseminates to the Thai tyre manufacturers.

In this research work the effects of rubber type (emulsion SBR, solution SBR, NR, BR, functionalized solution SBR, chloro-acetated NR) and their blends, reinforcing filler type (carbon black, silica) and their mixtures, type of sulphur vulcanisation system (CV, semi-EV, EV), crosslink density, functionalised plasticizer (MA-g-PB) and mixing conditions on energy dissipation of tyre tread compounds, which determines wet-grip properties of the tyres derived from them, were studied. However, only the effects of rubber type and selected blends will be reported here. The compound formulations were based on silica and conventional sulphur vulcanisation system which were found to be the best reinforcing filler and vulcanisation system for wet-grip property. [1] Use of hybrid fillers (silica and carbon black) were also studied but the results are reported elsewhere. [2]
2. Experimental

The compound formulation used in this study is shown in Table 1. Mixing was carried out by using a laboratory internal mixer (Brabender-Plasticorder 350E). Mixing was done in 3 steps, (1) all ingredients except curatives were mixed using the fill factor of 0.75, initial chamber temperature of 60°C, rotor speed of 40 rpm and mixing time of 10 minutes (2) the obtained compounds were mixed at 140°C, for 6 minutes to ensure complete reactions between rubber, silane coupling agent (Si-69) and silica (3) the compounds were finally mixed with curatives for 3 minutes. The optimum cure time (tc90) was determined using a moving die rheometer (TechPro MD+) at 160°C. Rubber-filler interaction was evaluated through the measurement of bound rubber content (BRC) by immersing approximately 0.5 g of the compound in 100 ml toluene at room temperature for 7 days. After filtration, the rubber-filler gel was completely dried and weighed. The BRC was then calculated using Equation (1).

\[
\%BRC = \left( \frac{W_{fg} - W_{F}}{W_{p}} \right) \times 100
\]  

where \(W_{fg}\) is the weight of rubber-filler gel, \(W\) is the weight of the test specimen. \(Ff\) and \(Fp\) are the weight fractions of filler and polymer in the rubber compound, respectively.

The tensile properties were determined by using a universal testing machine (Instron 3366, USA). Dependence of loss factor (tan \(\delta\)) on temperature was measured by dynamic mechanical analyzer (Gabo, Eplexor 25N, Germany) in tension mode. Temperature was scanned from -60 to 80°C at 2/min under static strain, dynamic strain and frequency of 1%, 0.15% and 10 Hz, respectively.

| Table 1. Compound formulation for the study of effects of rubber type |
|------------------------|------------------------|
| Materials              | Amount (part by weight)|
| SSBR or E-SBR or F-SSBR or NR or CNR or BR | 100 60 |
| NR or CNR or BR         | 0 40 |
| ZnO                    | 3 3 |
| Stearic acid           | 2 2 |
| 6PPD                   | 1.5 1.5 |
| TMQ                    | 1 1 |
| Paraffin wax           | 2 2 |
| Silica                 | 48 48 |
| TESPT (10% w/w of silica) | 4.8 4.8 |
| TDAE oil               | 3 10 |
| TBBS                   | 1.2 1.2 |
| TBzTD                  | 0.2 0.2 |
| Sulphur                | 2.2 2.2 |
3. Results and Discussion

Table 2 summarises results of tensile measurements for various vulcanised rubbers studied.

| Rubber type     | 10% Modulus (MPa) | 100% Modulus (MPa) | 300% Modulus (MPa) | Tensile strength (MPa) | Elongation at break (%) |
|-----------------|-------------------|--------------------|--------------------|------------------------|-------------------------|
| SSBR            | 0.65              | 3.45               | 14.4               | 19.5                   | 389                     |
| FS-SBR          | 0.68              | 4.26               | 18.8               | 23.1                   | 362                     |
| E-SBR           | -                 | 2.20               | -                  | 19.3                   | 499                     |
| NR              | 0.83              | 4.51               | 17.9               | 24.7                   | 433                     |
| CNR             | 0.84              | 5.20               | 19.5               | 23.2                   | 368                     |
| BR              | -                 | 1.73               | -                  | 13.2                   | 511                     |
| S-SBR/NR (60/40)| 0.74              | 3.60               | 13.9               | 19.6                   | 413                     |
| S-SBR/CNR (60/40)| 0.64              | 3.68               | 15.2               | 18.4                   | 357                     |
| S-SBR/BR (70/30)| -                 | 2.38               | -                  | 16.1                   | 414                     |
| E-SBR/NR (70/30)| -                 | 2.01               | -                  | 16.3                   | 515                     |
| E-SBR/BR (70/30)| -                 | 2.17               | -                  | 16.8                   | 479                     |
| F-SSBR/NR (60/40)| 0.76              | 4.00               | 16                 | 20                     | 369                     |
| F-SSBR/CNR (60/40)| 0.72              | 5.51               | 19.2               | 19                     | 292                     |

Results of bound rubber measurement are presented in Figure 1.

![Figure 1](image_url)

Figure 1. Bound rubber contents (a) SBR, NR, CNR (b) SBR/NR blends : 60/40

It can be seen from Table 1 that FS-SBR and CNR vulcanisates exhibit higher moduli and tensile strengths than those of S-SBR and E-SBR vulcanisates, due to higher interactions of FS-SBR and CNR with silica through reactions of functional group with silane coupling agent (TESPT) attached to the silica particles. This is supported by the values of the corresponding bound rubber given in Figure 1. Tensile properties of NR vulcanisates are comparable to those of the vulcanized FS-SBR and CNR samples whereas those of S-SBR vulcanisate are greater than those of E-SBR and BR vulcanisates. The moduli and tensile strengths of FS-SBR, S-SBR and E-SBR blended with NR or BR show lower values compared with the corresponding unblended rubbers.
The energy loss of the rubber vulcanisate or tan δ at 0°C, as measured by dynamic mechanical method, is used as a measure of good wet-grip properties. High value of tan δ at 0°C implies good wet-grip property. Results of tan δ measurement at 0°C of various vulcanised rubber compounds are shown in Table 3. It can be observed that FS-SBR give vulcanised tread compound having the best wet-grip property followed by S-SBR, CNR, E-SBR, NR and BR. Blends of SBR with lower ranking rubbers (CNR, NR and BR) also gave lower values of tan δ at 0°C or poorer wet-grip properties.

**Table 3. Values of tan δ at 0°C of various rubber vulcanisates studied**

| Rubber Type | Blend Ratio | tan δ at 0°C |
|-------------|-------------|-------------|
| FS-SBR      | -           | 0.726       |
| S-SBR       | -           | 0.538       |
| E-SBR       | -           | 0.237       |
| CNR         | -           | 0.307       |
| NR          | -           | 0.183       |
| BR          | -           | 0.147       |
| FS-SBR/CNR  | 60/40       | 0.552       |
| FS-SBR/NR   | 60/40       | 0.493       |
| S-SBR/CNR   | 60/40       | 0.527       |
| S-SBR/NR    | 70/30       | 0.458       |
| E-SBR/NR    | 70/30       | 0.231       |
| S-SBR/BR    | 70/30       | 0.286       |
| E-SBR/BR    | 70/30       | 0.147       |

4. **Conclusion**

From the study it was found that FS-SBR gave tyre tread compound with the best wet-grip property followed by S- SBR, CNR, E-SBR, NR and BR, as revealed by the values of tan δ at 0°C. Blends of SBR with lower ranking rubbers (CNR, NR and BR) also gave lower values of tan δ at 0°C or poorer wet-skid resistance.

5. **References**

[1] P. Sae-oui, K. Suchiva, C.Sirisinha, W. Intiya, P. Yodjun and U. Thepsuwan, Effects of Blend Ratio and SBR Type on Properties of Carbon Black-Filled and Silica-Filled SBR/BR Tire Tread Compounds, Advances in Materials Science and Engineering, Article ID 2476101 (2017)

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