Research Article

Material Selection for Natural rubber–Styrene butadine rubber Composite by Analytic Hierarchy Process

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Abstract

Natural Rubber (NR) has distinctive characteristics, namely, it possesses strength, reduces heat accumulation, and performs well at low temperatures, surpassing Styrene Butadiene Rubber (SBR). However, SBR has its own merits, such as resistance to cracking, wet road traction, and better weather resistance than NR. Consequently, in the automotive tire manufacturing industry, NR and SBR are commonly mixed in various ratios. Additionally, this blending aids in cost reduction during production. Thus, this research explores the mixing ratios between NR and SBR at 100/0, 75/25, 50/50, 25/75, and 0/100 using the Analytical Hierarchy Process (AHP) technique as a tool to manage values obtained from tests, including tensile strength, tear resistance, and 300% modulus. All these criteria are amalgamated into a single value to facilitate decision-making in selecting the most suitable ratios. It was found that 100/0 was the most preferable option, followed by 0/100, 75/25, 50/50, and 25/75.

Keywords: Natural Rubber, Styrene butadiene rubber, Rubber blend, Analytic Hierarchy Process.

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1. Introduction

One of the most important considerations in the selection of a polymer blend for improving mechanical properties is [1] natural rubber (NR) which is a natural product produced from the rubber plant possessing relatively good eco-friendly properties compared to other synthetic rubbers. There are two main types of rubber: natural rubber and synthetic rubber. The most popular types of natural rubber can be divided into 2 main forms as follows: Latex and Dry rubber. Latex which can be used to make almost any finished product. Latex is divided into 2 forms: Latex that has not been modified by any chemical or method to change the rubber molecules. Latex that has undergone chemical modification or irradiation to alter rubber molecules will come out as a static latex or prevulcanized latex. Dry rubber: It can be subdivided according to the production process into 4 types as follows: Sheet rubber or ordinary rubber is produced by traditional methods. There are rubber smoked sheets that will be pressed into cubes. Non-fumigated rubber sheet and desiccated rubber sheet. Crepe rubber is obtained by rolling scrap rubber in a crepe machine to remove various impurities. Technically Specified Rubber (TSR) is produced from fresh latex or may use clumped or dry rubber. Other types of rubber with unique production methods to produce products suitable for the molding of a particular product or intended to improve certain properties of natural rubber, such as rubber with a constant viscosity, thermoplastic rubber, epoxidized rubber. Powdered rubber and liquid rubber, etc. Synthetic rubber (SR) is a material similar in quality to natural rubber. It has resistance to oil. Chemical and heat resistant to high and age. Long-lasting use, synthetic rubber does not have the same elasticity as natural rubber, therefore, in its use, it is mixed into a material of similar quality to natural rubber. It has resistance to oil. Synthetic rubber does not have the same elasticity as natural rubber, so in its use, there is a mixture of natural rubber and synthetic rubber, which makes The product has the properties of natural rubber and synthetic rubber in the same body. There are several types of synthetic rubber, including styrene-butadiene rubber (SBR), butil rubber. These include butyl rubber, ethylene-propylene rubber (EPR), fluoro rubber, nitrile rubber, polychloroprene rubber, polysulfide rubber, polyurethane rubber and silicone rubber [2]. NR has been used in some environmentally restricted areas and tire applications [3]. The Thai rubber industry during 2021-2023 is estimated to continue to expand. The domestic market is likely to grow at approximately 4% per year due to continued industrial demand, especially tire production. Automotive parts, rubber gloves, medical rubber products that gradually recovers from Covid-19, as well as the use of rubber in other high-value industries that the government supports. As for exports of rubber products, it is expected that they will return to expand by approximately 3-4% in line with the global economic situation that will grow after the Covid-19 outbreak subsides, affecting the industrial sector, especially the automotive industry. Medical equipment, rubber gloves, will continue to have continuous demand along with the production of competing countries. There is still a downward trend in both Indonesia and Malaysia. This will help support the price of rubber to 60-65 baht per kilogram [4]. Elastomer blends are used for many objectives such as enhancing the performance characteristics of rubber products. NR was also blended with styrene-butadiene rubber (SBR) [5]. Currently, many NR/SBR vulcanizates are used in dynamic environments and some specific fields, which require NR/SBR with fine mechanical properties in both static and dynamic states [6]. Thus, inspections and analysis of the comprehensive mechanical properties of NR/SBR blends are necessary before their industrial application [6]. The mechanical properties of NR/SBR blends can be derived from the blend ratio. The materials selected for use in various circumstances must satisfy the function and the operating conditions of the component or the structure being designed. The properties which directly influence the option of material are chemical, physical, mechanical, and manufacturing properties. In this research, only mechanical properties will be focused on as these properties are related to the properties of rubber blend materials. The blending of two or more rubbers is a useful technique to improve certain properties not inherent in a single rubber [7]. This research consists of the compatible blend (NR/SBR) which in this case are 100/0, 75/25, 50/50, 25/75, and 0/100 respectively. These ratios of rubber blends have their own properties, advantages, limitations, and applications. The selection process can be defined by application requirements, possible materials, chemical, mechanical, physical principles, and selection [8]. The proportions of NR/SBR rubber mixtures were taken from the review literature for use in the study. However, it is difficult to analyze the regulation based on different properties obtained from different experiments. Therefore, it is necessary to combine all the criteria/properties into a single value to obtain a result by Analytical Hierarchy Process (AHP). It is an efficient tool for dealing with complex decision-making and may aid the decision-maker in setting priorities and making the best decision [9]. In this paper, the Analytic Hierarchy Process (AHP method) was applied to assess different rubber blends. Three criteria were used for analysis: tensile strength, tear resistance, and 300% modulus of rubber blend. Three various types of rubber blends were used for consideration: rubber based on natural rubber and styrene-butadiene rubber (SBR) [10]. Multi-Criteria Decision-Making (MCDM) for selection of materials is considered for new materials with complex application. One of the most famous MADM methods is AHP method [11]. Highlight that the main advantage of AHP is in treating the decision as a global system, synthesizing all available information and thus making previously complex decision processes more rational. [Application of the Analytic Hierarchy Process (AHP) to select high performance concretes]. The AHP method is often used to identify complicated decision-making problems in the manufacturing industry, waste management, environmental management, power, and energy industry, transportation industry, construction industry, etc. [12]. The decision process using the AHP method is made up of four steps [13]:

Step 1: Define the problem and determine the kind of knowledge sought.

Step 2: Structure a decision hierarchy that references decision-making goals in the following order: Objectives Intermediate criterion and a set of choices at the lowest level.

Step 3: Create a pair of comparative matrix sets. Each level of the matrix in the upper level is used to compare the elements in the lower level.

Step 4: Utilize the acquired priorities from the comparisons to weigh the priorities at the neighboring level. This process will continue until the final priority of the alternative is acquired. Pair-wise comparisons are used to learn the relative importance of each choice in terms of each criterion. In order to make pair-wise comparisons, a scale that specifies the number of times one element is important. To stand out from another element as opposed to the parent element is required.

2. Materials and Methods

2.1 Compounding formulations

The amount of these additives to be added is expressed in parts per hundred rubbers (phr), provides the weight of additives per 100 units of the base rubber. The compounding formulation design is shown in Table 1 . The rubber blends consist of many different components including Elastomers, Activators, Accelerators, Anti-degradants, and Vulcanization agents. Natural Rubber (NR) was blended in different ratios with Styrene Butadiene Rubber (SBR). The ingredients were homogeneously mixed in a two-roll mill. The duration of the mixing process was about 20 min for each ratio, then stored for 16 hours before testing. The distinct cure time at 160°C by a moving die rheometer MDR 2000 is in accordance with the ASTM D5289-95 test method. The rubber compounds were vulcanized at 160°C on a hot press.

Table 1 Compounding formulation design

Ingredients (phr)	RB1	RB2	RB3	RB4	RB5
NR	100	75	50	25	0
SBR	0	25	50	75	100
Activator	5	5	5	5	5
Accelerator	1.5	1.5	1.5	1.5	1.5

Table 1 Compounding formulation design (Continue)

Ingredients (phr)	RB1	RB2	RB3	RB4	RB5
Anti-degradants	1	1	1	1	1
Vulcanization agent	2	2	2	2	2

2.2 Sample preparation

The thickness of the rubber is about 2 mm., according to the ASTM D412-80 standard testing method. The dumbbell and crescent test pieces were prepared for physical testing. Mechanical properties for the prepared rubber blends, such as tensile strength, tear strength, and 300% modulus, were performed on a dumbbell shape specimen according to ASTM D412-68 [14] and ASTM D412-54 [15] using a universal testing machine (T-TS-01, Techpro) with a load cell capacity of 1 kN at a cross-head speed of 500 mm/min. At least five specimens were analyzed for the tensile strength, modulus at 300% strain (M300) and elongation at break. The results of these mechanical properties were agglomerated in one criterion, and a 9-level scale was established in the AHP method. The level scale of 1 ranked worst and the level scale of 9 ranked best and was used for the assessment of this criterion (Table 2). This scale was introduced by Prof. Thomas L. Saaty.

Table 2 Saaty's pair-wise comparison scale [13].

Verbal judgment	Numerical Value
Extremely important	9
	8
Very Strongly important	7
	6
Strongly important	5
	4
Moderately important	3
	2
Equally important	1

2.3 The Analytic Hierarchy Process

Hierarchical structure of decision making with a hierarchical analysis process, there is a process structure that imitates human thought.

1. Take note that the first level of the hierarchy is the objective: selection of NR/SBR compounding formulation. The next level in the hierarchy is constituted by the criteria: tensile strength, tear resistance, and 300% modulus. The third level consists of the available alternatives which in this case are the proportion of NR and SBR:100/0 (RB1), 75/25 (RB2), 50/50 (RB3), 25/75 (RB4), and 0/100 (RB5) respectively. The hierarchical structure is illustrated in Figure 1 as shown below.

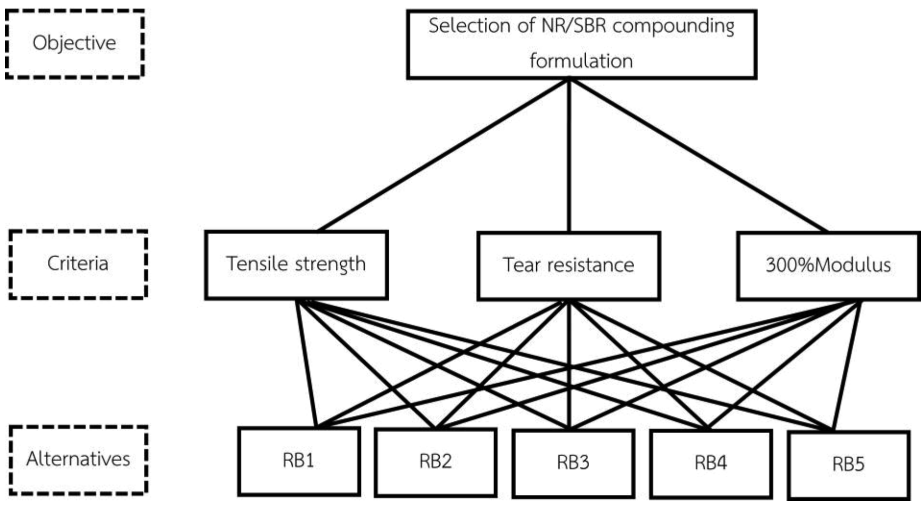

Figure 1 Hierarchical structure

Table 3 The mechanical property results for different formulation of NR/SBR blends

NR/SBR	Tensile Strength (MPa)	Tear Strength (N/mm)	300%Modulus (MPa)
100/0	28.22	29.25	2.25
75/25	23.01	22.48	1.90
50/50	15.52	17.94	1.69
25/75	3.42	16.19	1.69
0/100	1.76	10.70	1.55

2. Take the values from Table 3 Let's give a score of 1-9 (Table 2) by comparing with Tensile Strength, Tear Strength and 300% Modulus properties according to the standards of natural rubber. natural rubber mixed with styrene butadiene rubber and styrene butadiene rubber from Material Selection Charts. The evaluation criteria of each criteria will be based on data from NR, SBR and Material Selection Methods [16]. Comparative diagnosis of the importance of criteria in deciding to compare different criteria. It is a pairwise comparison (pairwise comparison), which is a comparison to determine the importance weight between criteria in pairs. Using numbers instead of values to lead to the calculation of the total importance score of each alternatives. Appropriate tools for use in pairwise comparison include using a matrix table.

3. In the next step, in order to validate the results of the AHP, the consistency ratio (CR) is calculated using the formula, CR = CI/RI in which the consistency index (CI) is, in turn, measured through the following formula. The value of RI is related to the dimension of the Matrix. It should be noted that consistency ratio lower than 0.10 verifies that the results of comparison are acceptable.

4. The priority value of each criterion is used in the calculation together with the Priority of alternatives to find the weight value. The importance of choices used in decision making.

3. Result

The comparison between the criteria (Tensile strength, Tear resistance, 300%Modulus) is shown in Table 4. It is a pairwise comparison (Pair Wise Comparison). It is a comparison to determine the importance weight between criteria in pairs, using numbers to represent the values, leading to the calculation of the total importance score of each alternative. which has the values shown in Table 5. The decision-makers were fairly consistent in ranking the attributes. Indeed, the consistency indexes have been less than the threshold value of 0.1. The consistency index (CI) was 0.007; the consistency ratio (CR) was 0.013 because it was lower than 0.01. The criteria weights, determined through pair-wise comparisons using AHP (Table 4), reveal that tensile strength holds the highest importance (0.391), followed by 300% modulus (0.341) and tear resistance (0.268). This implies that tensile strength is considered more critical than the other factors in the context of compounding formulation design.

Table 4 Paired comparison matrices results and relative weights of attributes (CI=0.007, CR=0.013).

Selection of compound formulation	Tensile strength	Tear resistance	300%Modulus
Tensile strength	1.00	1.29	1.29
Tear resistance	0.77	1.00	0.70
300%Modulus	0.77	1.44	1.00

Table 5 Calculation of criteria.

Selection of compound formulation	Tensile Strength	Tear resistance	300%Modulus	Priority
Tensile Strength	0.393	0.347	0.433	0.391
Tear Strength	0.304	0.268	0.233	0.268
300%Modulus	0.304	0.385	0.334	0.341

The normalized weights of each criterion are found in all five alternatives and enlisted in Tables 6-8. In order to find the normalized values for a single criterion, experimental results are compared to all the alternatives. It is done similarly to forming the pair-wise comparison matrix. The pairwise comparisons for each rubber blend concerning tensile strength, tear resistance, and 300% modulus provide a detailed analysis.

Table 6 Comparison of rubber blend with respect to tensile strength (CI=0.065, CR=0.058).

Tensile strength	RB1	RB2	RB3	RB4	RB5	Priority
RB1	1.00	2.54	2.54	2.54	2.54	0.371
RB2	0.39	1.00	2.07	2.07	2.07	0.227
RB3	0.39	0.48	1.00	1.40	1.40	0.144
RB4	0.39	0.48	0.72	1.00	0.31	0.098
RB5	0.39	0.48	0.72	3.25	1.00	0.161

Table 7 Comparison of rubber blend with respect to tear resistance (CI=0.018, CR=0.016).

Tear resistance	RB1	RB2	RB3	RB4	RB5	Priority
RB1	1.00	1.05	1.05	1.05	1.05	0.205
RB2	0.95	1.00	0.81	0.81	0.81	0.172
RB3	0.95	1.24	1.00	0.65	0.65	0.172
RB4	0.95	1.24	1.55	1.00	0.58	0.201
RB5	0.95	1.24	1.55	1.72	1.00	0.249

Table 8 Comparison of rubber blend with respect to 300%modulus (CI=0.002, CR=0.002).

300% Modulus	RB1	RB2	RB3	RB4	RB5	Priority
RB1	1.00	1.06	1.06	1.06	1.06	0.210
RB2	0.94	1.00	0.90	0.90	0.90	0.185
RB3	0.94	1.11	1.00	1.00	0.80	0.192
RB4	0.94	1.11	1.00	1.00	0.80	0.192
RB5	0.94	1.11	1.25	1.25	1.00	0.220

The priority values demonstrate the relative performance of each blend in the specified criteria, leading to an overall ranking. as shown in Table 9. Considering the mixing ratio of 2 types of rubber (RB2 , RB3 , RB4), it was found that RB1 provided mechanical properties (Tensile strength, Tear resistance, 300% Modulus) that were more outstanding than RB3 and RB4. RB2 stood out in Tensile strength properties. RB2 stood out in properties. Tensile resistance RB3 and RB4 are outstanding in their properties of 300% Modulus [17].

Table 9 Comparison of local priorities of the alternatives with respect to each criterion.

Alternatives	Tensile strength	Tear resistance	300%Modulus	Priority
RB1	0.371	0.205	0.210	0.2716
RB2	0.227	0.172	0.185	0.1979
RB3	0.144	0.172	0.192	0.1679
RB4	0.098	0.201	0.192	0.1577
RB5	0.161	0.249	0.220	0.2047

4. Discussion and Conclusion

The application of the Analytic Hierarchy Process (AHP) in selecting the NR/SBR compounding formulation for a high-performance rubber blend has yielded insightful results. The methodology involved the development of pair-wise comparison matrices for criteria with respect to the goal, ultimately providing priority vectors for both the criteria and sub-criteria. The key findings and conclusions of this work are summarized as follows:

The study considered three critical criteria-tensile strength, tear resistance, and 300% modulus. The AHP method facilitated the determination of the importance of each selection criterion. The ranking of alternatives based on their overall priority reveals RB1 as the most preferable option, followed by RB5, BA2, RB3, and RB4. RB1 is the highest value and the most preferable (overall priority = 27.16%) compared to RB2 (overall priority = 19.75%), RB3 (overall priority = 16.79%), RB4 (overall priority = 15.77%), and RB4 (overall priority = 20.47%). Considering the mixing ratio of 2 types of rubber (RB2, RB3, RB4), it was found that RB1 provided mechanical properties (tensile strength, tear resistance, 300% modulus) that were more outstanding than RB3 and RB4. RB2 stood out in tensile strength properties. RB2 stood out in properties. tear resistance RB3 and RB4 are outstanding in their properties of 300%modulus [18]. Therefore, natural rubber (RB1) can be used to produce materials that require good frictional and wear properties and also chemical resistance, particularly in the field of automobiles, aircraft and chemical industry [19] but it is easy to age in the air and becomes sticky when heated. It is easy to expand and dissolve in mineral oil or gasoline. It is alkali resistant but not strong acid resistant [20]. Styrene-butadiene rubber (RB5) offers excellent abrasion resistance and crack endurance. It also ages well and delivers good compression set and water resistance [21]. The disadvantages of styrene-butadiene rubber are its poor resistance to sunlight and ozone [22]. It was previously shown that tensile strength, elastic modulus, elongation at break, hardness and wear resistance of NR/SBR composites increase with increasing NR content and prevulcanization time [23]. AHP is a very effective method in determining a problem like selecting the best optimal mix, which involves various parameters for ranking. However, it is difficult to analyze the performance based on different properties obtained from different experiments. Hence it is necessary to combine all the criteria/properties into a single value to obtain a result by a technique called Analytical Hierarchy Process (AHP). It serves as a potent instrument for navigating intricate decision-making processes, facilitating the establishment of priorities and optimal choices. Moreover, the AHP integrates a valuable method for assessing the coherence of the decision maker's judgments, thereby mitigating biases within the process. decision making process. However, decision-makers should carefully analyze the criteria's weights and the possibility of inconsistent decision-making, as the AHP technique has significant drawbacks. The AHP technique's key advantage in material selection is its capacity to manage complex decision-making scenarios including several criteria and subjective preferences. The approach allows decision-makers to weigh the relative importance of many criteria while accounting for both qualitative and quantitative elements. Nonetheless, there are a few drawbacks to the AHP technique, including the difficulty of identifying the relative weights of the criteria and the possibility of inconsistent decision-making due to individual preferences [24].

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