ASSESSMENT OF RUBBER BLENDS USING MULTI-CRITERIA ANALYSIS

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Abstract: The intensive technology development, as well as the increase in the number of inhabitants, results in a significant consumption of natural and energy resources, as well as the daily generation of increasing amounts of waste. Because of that the significant efforts are being made in finding new ways of materials recovery from waste, as well as the application of secondary raw materials in the production of products and for alternative purposes. The rubber blend consists of different components: elastomers (rubber - natural or synthetic); fillers; vulcanization activators; accelerators of vulcanization; antioxidants, etc. Most of these components are obtained from non-renewable resources. Given that rubber is a material from which a large number of products (primarily tires) are produced, replacing some of the components with recycled materials would contribute to the preservation of natural resources, as well as the environmental protection. A large number of researches are carried out with the aim of using secondary raw materials (recycled rubber, polyurethane waste powder, waste powdered glass, waste laser toners etc.) is as a filler in rubber blends. These materials can be used as substitutes for certain components of rubber blends due to their similar chemical composition. The reason why these materials were taken into consideration lies in their availability, as well as their impact on the environment. The aim of this work is to evaluate different rubber blends filled with recycled materials using multicriteria analysis, i.e., the Analytic Hierarchy Process (AHP) method. Four different types of rubber blends were taken in to consideration: virgin rubber filled with 20% of recycled rubber powder, virgin rubber filled with 20% of polyurethane waste powder from electrical and electronic waste equipment, virgin rubber filled with 20% of waste powdered glass with an average particle size smaller than 63 μm, and virgin rubber filled with 20% of waste laser toner. Criteria used for rubber blends assessment are: availability of raw materials, mechanical properties of rubber blends, environmental impact of raw materials, and raw materials price. The used procedure of the AHP method implies the formation of a hierarchical structure, pair-wise comparison, determination of weighting factors, and alternatives ranking. The obtained results show that rubber blend filled with 20% of recycled rubber is best ranked with ranking priority of 52.7%, because of the best mechanical properties of rubber blend. In order to examine the impact of the criteria weighting, a sensitivity analysis was performed, which confirmed the obtained results that in every case the Rubber blend 1 is the best ranked.
Keywords: Rubber blends, recycled rubber powder, polyurethane waste powder, waste powdered glass, multi-criteria analysis.

1. INTRODUCTION

The intensive technology development, as well as the increase in the number of inhabitants, results in a significant consumption of natural and energy resources, as well as the daily generation of increasing amounts of waste. Because of that the significant efforts are being made in finding new ways of materials recovery from waste, as well as the application of secondary raw materials in the production of products and for alternative purposes (Fazli & Rodrigue, 2020).

Various researches have been carried out in order to examine the influence of certain recycled materials on the properties of rubber compounds (Kaliyathan et. Al, 2019). Some authors examined the influence of recycled and reclaimed rubber as a filler on the properties of rubber blends, varying their share (5%, 10%, 20%) in the rubber mixture (Đekić et al, 2012). Also, research was carried out in which the possibility of improving the mechanical properties of rubber blends filled with mechanochemical modified recycled rubber (Đekić et.al, 2015), and some authors also performed a cost-benefit analysis of modification of recycling rubber powder (Đekić et.al, 2018). A group of authors evaluated rubber blends filled with recycled and reclaimed rubber from different aspects: technical, economic and environmental (Đekić et. al, 2016). In addition, research was conducted in which the effects of other recycled materials on the properties of rubber blends were investigated. The authors (Đekić et.al, 2017) examined the influence of polyurethane waste on the properties (hardness, wear resistance, tensile strength, and tear resistance)

of rubber blends and concluded that filling the rubber mixture with up to 5% polyurethane powder has the least impact on the mechanical properties of rubber blends. The possibility of using waste glass powder as a replacement for silicate filler in rubber mixtures was investigated and it was concluded that this material has the greatest impact on resilience resistance (Đekić et. al, 2019). Some authors also investigated the use of waste laser toner as a non-active filler in rubber compounds due to their similar chemical composition (Milutinović & Đekić, 2020).
In this paper multi-criteria analysis i.e., the Analytic Hierarchy Process (AHP) method, was applied in order to assess rubber blends filled with different raw materials from different criteria. Criteria used for analysis are: availability of raw materials, mechanical properties of rubber blends, environmental impact of raw materials, and raw materials price. Four different rubber blends were developed: virgin rubber filled with 20 % of recycled rubber powder, virgin rubber filled with 20 % of polyurethane waste powder from electrical and electronic waste equipment, virgin rubber filled with 20 % of waste powdered glass with an particle smaller than 63 μm as a replacement for silicate filler and virgin rubber filled with 20 % of waste laser toner.

2. MATERIALS AND METHODS

2.1 The Analytic Hierarchy Process

Multicriteria analysis is an integrated method used for decision support. Multi-criteria analysis methods allow the participation of different groups of decision-makers even with opposing goals, and also allow the use of a large number of different criteria.
The Analytic Hierarchy Process (AHP) procedure implies the formation of a hierarchical structure, pair-wise comparison, determination of weighting factors, and alternatives ranking (Sipahi & Timor, 2010). Procedure The AHP method involves four steps in the decision-making process: 1) defining the decision goal; 2) forming the hierarchy structure according to the goal; 3) forming the pair-wise comparison matrices; 4) priorities weighting and alternative ranking (Saaty, 2008).

2.2. Rubber blends composition

In the production of rubber blends, the elastomer is mixed with other ingredients, and after that cured. The rubber blend is prepared on the basis of the recipe, which contains an exhaustive list of all the constituent elements of the blend and stirring the blend, i.e., the order of mixing elastomer and ingredients. The rubber blends may consist of different components: elastomer - rubber (natural or synthetic); fillers; vulcanization activators; vulcanization retarders; vulcanization funding; vulcanization accelerators; antioxidants; softeners and plasticizers, and ingredients for special purposes (Đekić et al, 2012).
Uncured blends are further processed through processes that involve usage different machines; extruders, calenders, injection-molding machines, continuous vulcanization units, and curing presses.

3. EXPERIMENTAL RESEARCH

During the rubber blends assessment in terms of different criteria, four rubber blends alternatives were developed. Also, four criteria were used: availability of raw materials, mechanical properties of rubber blends, environmental impact of raw materials, and raw materials price.

3.1. Alternatives of Rubber Blends

The following rubber blends have been developed:
Rubber blend 1: virgin rubber filled with recycled rubber powder. In Rubber blend 1, virgin rubber blend was filled 20% with recycled rubber powder made from tires and the particles size was less than 250 μm.
Rubber blend 2: virgin rubber filled polyurethane waste powder from electrical and electronic equipment. Polyurethan waste powder was obtained in waste refrigerated and freezer recycling, with impurities less than 0,05%, and the particles less than 250 μm. In this rubber blend virgin rubber was filled with 20 % of polyurethan waste powder.
Rubber blend 3: virgin rubber filled with waste powdered glass with an particle less than 63 μm. In this rubber blend virgin rubber was filled with 20 % of waste glass powder.
Rubber blend 4: virgin rubber filled with waste laser toner. Waste laser toner is a powder mixture of polypropylene, fumed silica, and various minerals. In this rubber blend virgin rubber was filled with 20 % of waste laser toner.

3.2. Criteria Selection and Evaluation

Four criteria were chosen for the rubber blends assessment from different aspects: availability of raw materials, mechanical properties of rubber blends, environmental impact of raw materials, and raw materials price.
Availability of raw materials: This criterion takes into account the availability and quantities of raw materials added as filler to the rubber compound. According to data from the literature, the highest available quantities of secondary raw materials are waste packaging glass and waste rubber. The smallest available quantities are waste laser toner. The 9-level scale (1 – the less available, 9 – the most available) was used for the assessment of this criterion.

Mechanical properties of rubber blends: Different mechanical properties of rubber blends are measured: hardness, tensile strength, elongation at break, wear, and compression set in order to determine the mechanical properties. Measurements of the mechanical properties of rubber compounds were performed according to appropriate standards, using calibrated devices. The obtained results of those mechanical properties were agglomerated in one criterion, and 9-level scale (1 – the worst, 9 – the best) was used for the assessment of this criterion.
Environmental impact of raw materials: This criterion takes into account the impact of the raw material on the environment. Waste toner is hazardous waste because it contains carcinogenic substances and the particle size is less than 10 μm and it has the most negative impact on the environment. Polyurethan waste powder may contains certain amounts of freon (since it is obtained by recycling old electrical and electronic devices) which can have a negative impact on the ozone layer. Rubber is not a hazardous waste, but it is generated in large quantities and occupies a large volume, which reflects its negative impact on the environment. Packaging glass is an inert waste and cannot be decomposed in landfill (and it is generated in large quantities), so it remains in the environment for a long time. The 9-level scale (1 - the biggest negative impact, 9 – the least negative impact) was used for the assessment of this criterion.
Raw materials price: Criterion Raw materials price was calculated based on the raw materials current market price. Values of selected criteria are presented in Table 1.

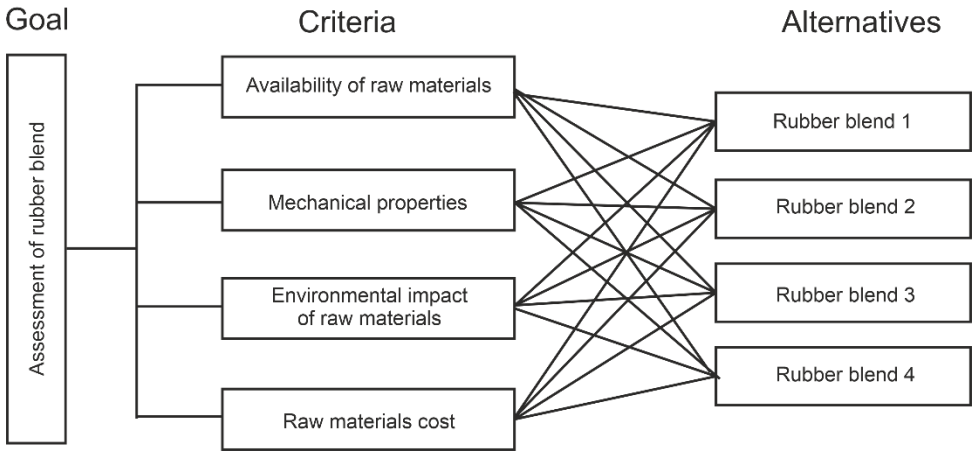
Table 1. The selected criteria values.

Criteria	Rubber blend 1	Rubber blend 2	Rubber blend 3	Rubber blend 4
Availability of raw materials	8	7	9	5
Mechanical properties of rubber blends	9	8	6	7
Environmental impact of raw materials	7	8	5	9
Raw materials price (€/t)	130	0	30	0

3.3. The hierarchical structure

The formed hierarchical structure is presented in Figure 1: goal, criteria and alternatives.

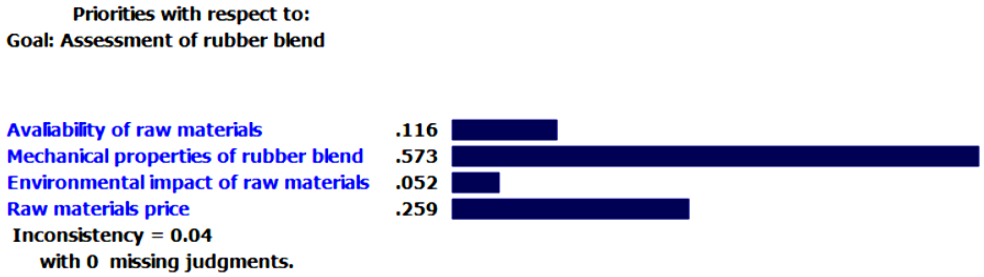
Figure 1. The formed hierarchical structure.



4. RESULTS AND DISSCUSIONS

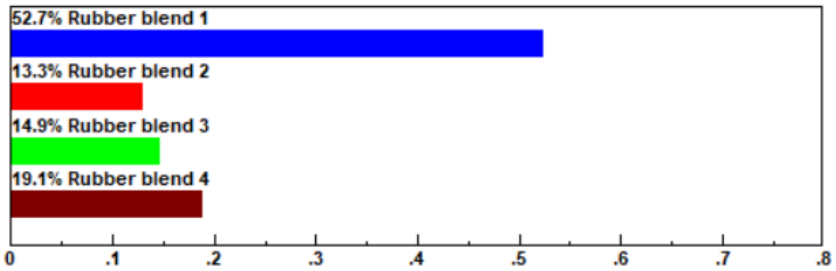
After implementing the procedure of the AHP method and pairwise comparison, the weighting factors of the criteria were calculated and shown in Figure 2. The highest priority is given to the mechanical properties of rubber blends.

Figure 2. Criteria priorities.



The obtained results show that Rubber blend 1 (filled with recycled rubber) is the best ranked with priority ranking of 52,7%, because of the best mechanical properties of rubber blend (Figure 3).

Figure 3. Alternative rubber blends ranking for evaluated criteria weight.



According to the performed analysis, the initial assumptions reached by a large number of researchers were confirmed, that due to the same chemical composition of recycled rubber and the base mixture, the best ranking alternative is rubber blend filled with recycled rubber powder, although the size of the particles has a significant influence. In second place is rubber blend filled with waste laser toner because it has a polymer base, a very fine particle, and a developer is also applied to the toner particles to strengthen the chemical bond. In third place is rubber blend filled with waste powdered glass due to the fineness of the particles, while in last place is rubber blend filled with waste powdered polyurethane.

4.1. Sensitivity analysis

In order to determine the impact of criteria weighting priorities on the ranking of alternatives, a sensitivity analysis is performed. Sensitivity analysis involves examining different cases in which criteria weighting priorities are changed. If the same ranking result is obtained in most cases, the result is considered to be robust.

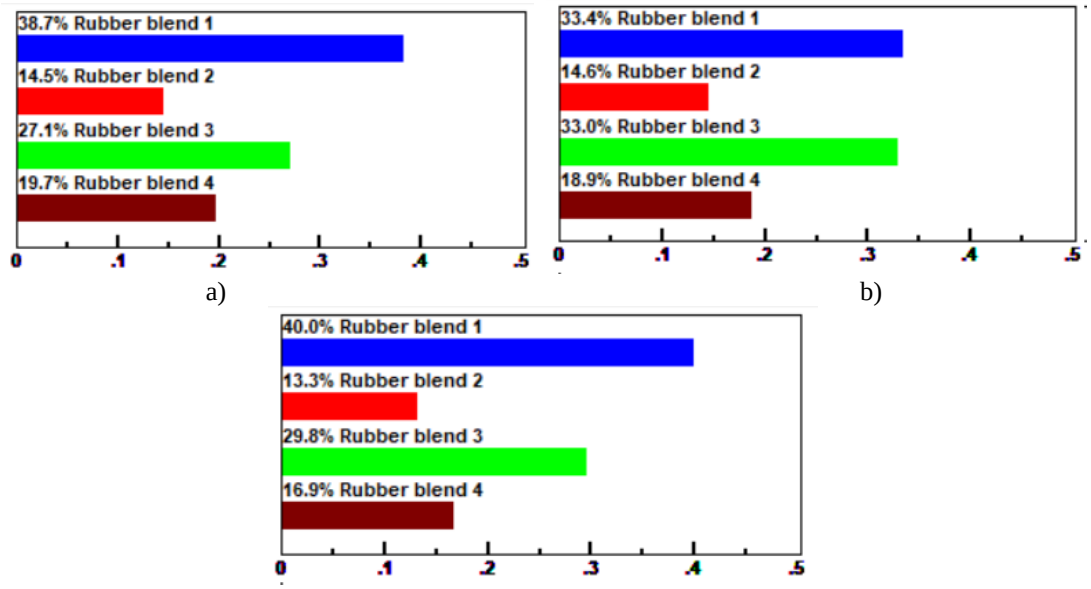
As part of this research, the following cases were taken into consideration:

Case 1: An equal weighting factor of 25% are given to all criteria.

Case 2: Criteria Availability of raw materials and Environmental impact of raw materials have a weighting factor of 70% (each of them has a weighting factor of 35%), while others have a weighting factor of 30%.

Case 3: Criterion Mechanical properties of rubber blends has a weighting factor of 10%, while others have a weighting factor of 90% (each of them has a weighting factor of 30%).

Figure 4. The sensitivity analysis results: a) Case 1, b) Case 2, c) Case 3.



In the Case 1 when an equal weighting factor of 25% are given to all criteria, Rubber blend 1 has the first ranking priority of 38.70%. In the Case 2 then criteria Availability of raw materials and Environmental impact of raw materials have a weighting factor of 70%, Rubber blend 1 and Rubber blend 3 also have the first ranking priority of 33.00% due to the most available secondary raw materials (rubber and glass) regardless to negative impact on the environment. The same results were obtained in Case 3 criterion Mechanical properties of rubber blends has the smallest weighting factor of 10%, while other criteria have a weighting factor of 90% (each criteria have a weighting factor of 30%).

5. CONCLUSIONS

Rubber blends are complex materials that consist of different components (elastomer, active, inactive, and special ingredients). The production of components that are included in the composition of rubber compounds implies the consumption of non-renewable material and energy resources, so ways are constantly being sought to replace certain components of rubber compounds with secondary raw materials. One of the ways of using secondary raw materials (recycled rubber, polyurethane waste powder, waste powdered glass, waste laser toners etc.) is as a filler in rubber blends.

In order to assess rubber blends, multi-criteria analysis i.e., the Analytic Hierarchy Process, was applied. Four different rubber blends were developed: virgin rubber filled with 20 % of recycled rubber powder, virgin rubber filled with 20 % of polyurethane waste powder from electrical and electronic waste equipment, virgin rubber filled with 20 % of waste powdered glass, and virgin rubber filled with 20 % of waste laser toner. Criteria used for rubber blends assessment are: availability of raw materials, mechanical properties of rubber blends, environmental impact of raw materials, and raw materials price.

The obtained results show that the Rubber blend 1 (filled with recycled rubber) is the best ranked with ranking priority of 52,7%, because of the best mechanical properties of rubber blend. Conducted sensitivity analysis also show that Rubber blend 1 ranked the first.

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