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Recycling of post-consumer tires with metallic cord by magnetic shock method***

This presentation considers experimental results of metal and rubber separation inside post-consumer tires by magnetic shock method and some calculations of commercial tire recycling with the method. An electric pulses installation with energy less than 9 kJ and only 2% efficiency had realized metal separation in samples from tire with sizes about 20x4 cm². Energy consumed at the separation is less than 0.01 kWh per 1 kg of tire weight.

Full recycling technology includes further mechanical crushing and modification of rubber crumb. As the result one can have the material suitable for the vulcanization directly into rubber goods. Such parameters of commercial recycling as estimated cost and cost of 1 ton of the modified rubber crumbs are given.

Key words: post-consumer tire recycling, tires with metallic cord, magnetic shock method

Recykling zużytych opon z kordem stalowym metodą wstrząsu magnetycznego

Komunikat obejmuje wyniki badań oddzielania metalu od gumy wewnątrz zużytych opon metodą wstrząsów magnetycznych oraz obliczania kosztów recyklingu opon przeprowadzonego tą metodą w skali technicznej.

W przypadku oddzielania metalu z wycinka opony o wymiarach 20x4 cm² wystarczy pulsacja elektryczna o energii mniejszej niż 9 kJ i wydajności zaledwie 2%. Zużycie energii na oddzielenie metalu jest mniejsze niż 0,01 kWh na 1 kg masy opony.

Technologia recyklingu obejmuje dalsze rozdrabnianie mechaniczne i modyfikację zmielonej gumy. W wyniku całego procesu uzyskuje się materiał odpowiedni do formowania i wulkanizacji wyrobów gumowych.

Podano parametry ekonomiczne procesu recyklingu, takie jak koszty i cenę 1 tony miału gumowego.

Słowa kluczowe: recykling zużytych opon, opony z kordem stalowym, metoda wstrząsu magnetycznego

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1. Introduction

Since the using of tires reinforced by metallic wires, utilization of these tires with a purpose of reusing its raw materials is remained a difficult problem.

The direct mechanical crushing of tires with metallic cord is characterized by high amortization of equipment and high-energy consumption (up to 1.5 kWh per 1 kg of rubber crumb). The resulting crumb has got a few metallic inclusions (0.01% - 0.1%).

The cryogenic method permits to obtain rubber crumb without the metallic inclusions. However, the crumb lost its elasticity and the energy consumption is higher (up to 2.5 kWh per 1 kg of rubber crumb).

Others methods one could use such as the microwave heating of metal or different explosive methods still didn’t give satisfactory results.

In this work we examine a new magnetic shock method of metal separation inside a tire. We also present some calculated results of commercial tire recycling.

2. Experimental results

A high-voltage (up to 4 kV) electric pulse installation had been devised for creating electric discharges with energy about 9 kJ (less than 0.003 kWh). A period of electric fading oscillations was about 200 ms.

Experimental study of the metal separation has been realized in the following way. A sample cut out from a tread part of car tire (sizes about 20x4 cm²) was placed in special means. The means had got two conducting fixing members that connected all cord wire ends from one layer of metallic cord to the installation’s high-voltage outlets. One of the members had got a long conductive protrusion and all cord wires of the sample had been arranged parallel to the protrusion.

A high-voltage electric pulse had gated in opposite directions through the cord wires and said protrusion that causes a magnetic shock between the wires and the rubber in the sample.

The cord wires separated from adjoining rubber have got yellow color. Which means a thin film of brass is remained around cord wires. So, the separation has been done very clean.

Under the action of electric pulse the cord wires had got heating. The average temperature of the wires was raised to 500°C but the rubber has got heating to 35-40°C only.

In the experiments we have done a ratio between electric pulse energies consumed to the magnetic shock and to the metal heating had been equal about 1/50. This is only 2% efficiency of the installation. Despite this, the metal separation has been realized in the samples in size of about 1/30 of a car tire. So, the energy consumption to metal separation by magnetic shock is less than 0.01 kW per 1 kg of a tire weight even in our experiments.

A devise realized the magnetic shock for a full tire is described in [1].

3. Recycling method

According to the recycling method a tire’s rubber released from metallic cord is crushed in crumb by usual mechanical equipment.

The energy consumed in the crushing is about 0.3-0.5 kW per 1 kg of the crumb. That is in 2-3 times less than one would use a usual mechanical equipment, because, in this case, the energy is consumed both to crushing metal and rubber together and to their additional separation.

After crushing the crumb can be modified in a special apparatus. The modification is realized at room temperature and modified additions are present. As the result one could have got a raw material fitting to vulcanization in rubber goods directly. The energy consumed on this is less than 0.02 kWh per 1 kg of modified crumb.

Let us give the tire-recycling diagram in Figure 1.

![Figure 1. Tire-recycling diagram](image-url)
As compared to others methods, our one has the following advantages:

- Energy consumption is lower in 2 ... 3 times;
- Waste material is practically absent (mechanical or cryogenic technologies give now about 30% of waste);
- Obtained rubber crumb is of higher quality, because it does not lose its elasticity as with cryogenic processing, and it has not metal inclusions as with mechanical crushing;
- The modification of crumb permits us to obtain the raw material one could use instead a primary rubber in most of rubber goods.

This recycling method is an appropriate technology due to absence of large rubber heating or cooling.

4. Calculated results of the commercial recycling

The commercial realization of tire recycling consists of three stages. These are a pilot electric-pulse installation, a pilot factory for car tire recycling and than a factory for truck tire recycling. The first stage, a pilot electric-pulse installation, would be needed for a testing of recycling method, a training of electric-pulse equipment and an optimization of the metal separation process. This stage duration will be about six months. The second stage (about nine months of duration), a pilot factory of car tire recycling, would help us to test and control the recycling process in general. At last, the third stage, a creation of the truck tire-recycling factory, will complete the realization of the first pilot recycling factory and will last nine months.

Let us represent the estimated cost for creating the first pilot-recycling factory.

The first production line (car tire recycling) will start after 15 months of the project duration. The factory output will be about 300 kg of modified rubber crumb per hour (or about 100 tons per month) during next 9 months. After 24 months from the project duration the factory output will be increased up to 600 tons of modified rubber crumb per month.

Let us give a calculated cost of 1 ton of the modified rubber crumb:

Salary was calculated in the following way:
An average salary of an employee will be $1500 per month. The staff will include about 10 persons. The factory output will be about 600 tons of a modified rubber crumb per month. So, a part of wages in crumb’s cost will be equal to $1500x10/600=$25.

Equipment depreciation was calculated in the following way:
20% of annual equipment depreciation will be about $650000/5=$130000. The annual output is equal to 6000 tons of crumb. So, a part of expense for equipment depreciation in crumb’s cost will be equal to $130000/6000=$25.

Production costs (including electrical energy) was calculated in the following way:
Energy consumption is calculated in such way: $0.05 (it is a price of 1 kWh)x400 (it is the energy consumption of 1 ton crumb produced) = $20. Let other costs (heating, illumination, transport and so on) are equal $10. So, in total, production cost will be added up to $20+$10=$30.

<table>
<thead>
<tr>
<th>N°</th>
<th>Cost estimate (in thousands of US dollars)</th>
<th>First stage, the electric-pulse installation</th>
<th>Second stage, the pilot factory for car tires</th>
<th>Third stage, the pilot factory for truck tires</th>
<th>Total</th>
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<tbody>
<tr>
<td>1</td>
<td>Wages</td>
<td>25</td>
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<td>2</td>
<td>Charge extra wages</td>
<td>12.5</td>
<td>30</td>
<td>30</td>
<td>72.5</td>
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<td>3</td>
<td>Equipment</td>
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<td></td>
<td></td>
<td></td>
</tr>
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<td></td>
<td>electric pulse</td>
<td></td>
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<td></td>
<td>for modification</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Materials</td>
<td>24</td>
<td>40</td>
<td>30</td>
<td>94</td>
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<td>Other direct costs</td>
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<td>3</td>
<td>9</td>
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<td>100</td>
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<td>8</td>
<td>Overhead</td>
<td>7.5</td>
<td>40</td>
<td>60</td>
<td>107.5</td>
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<tr>
<td>9</td>
<td>Estimated total cost</td>
<td>75</td>
<td>530</td>
<td>650</td>
<td>1255</td>
</tr>
</tbody>
</table>

Table 1. Estimated cost
All parts of calculated cost is given in Table 2.

Table 2. Calculated cost of 1 ton of the modified rubber crumbs

<table>
<thead>
<tr>
<th>№</th>
<th>Component parts of the cost</th>
<th>(in US dollars)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Wages</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>Charge extra wages (40% from wages)</td>
<td>10</td>
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<tr>
<td>3</td>
<td>Equipment depreciation</td>
<td>25</td>
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<tr>
<td>4</td>
<td>Production costs (including electrical energy)</td>
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<td>5</td>
<td>Cost</td>
<td>90</td>
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<tr>
<td>6</td>
<td>Total taxes</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>Total cost</td>
<td>110</td>
</tr>
</tbody>
</table>

The modified rubber crumb could replace a primary rubber. Market price of the rubber is now about $1000-2000 per 1 ton. One could sell the modified rubber crumb at the price of $300-400 per 1 ton. In this case the selling profit will be large enough to increase the estimated cost for 1 year of the factory’s work.

5. Conclusion

The magnetic shock method of tire recycling will be able to solve the problem of tire recycling cost-efficiently and with ecological safety.

Due to complete separation of metal is realized:

- the energy consumption is materially reduced (less than 0.5 kWh per 1 kg of the crumb);
- the equipment depreciation is reduced;
- the rubber crumb will be much better and cheaper than present rubber crumb.

References

1. A. Bedjukh, T. Parubochya, V. Butko. „Devise for destroying tires with metal cord using electric discharges”. International claim for invention rights. Number of international publication is WO 99/51412 from 14.09.1999