Processing of rubber waste with the steel cord content

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Abstract

This thesis presents the main issues connected with the processing of tire waste. It is divided into two parts – an introduction and state-of-the-art and an experimental section.

The introduction begins by introducing the historical background of the rubber and tire industry and presents the tire waste characteristics along with the legal background of management of such waste. Afterward, the basic methods for managing the problem of tire waste are presented – retreading of worn tires, usage of entire tires in many types of constructions, granulate and reclaim preparation from used tires and energy recovery. The next chapter presents other solutions for such waste – like the production of alternative fuels, in particular by thermal processes, usage in road construction and other applications.

The experimental section focuses on pyrolysis of the tire waste. Examined waste, given for tests by SUEZ Company, is a waste generated during the process of tires manufacturing. It was supplied in the form of stripes of pre-vulcanised rubber with steel cord inside. After conducting the pyrolysis, samples of remaining char for all pyrolysis temperatures that were applied, are subject to the further tests – for the measurement of the calorific value and elemental composition: carbon, hydrogen, nitrogen, chlorine, and sulphur. On the sample analysed tests were also made to determine the volatile and combustible matter contents, and sieve analysis for the combusted sample. The data that was obtained was averaged, recalculated in respect of mass loss occurring during the rise in temperature of the pyrolysis process and further analysed to extract conclusions about the sustainable way of managing the tire waste.
Keywords: waste, tire, pyrolysis, rubber, recycling

1. Introduction

The life on Earth is threatened by many problems – draughts, floods, diseases, growing temperature connected with the melting of glaciers and so on – rising level of water, degradation of fossil resources, severe environmental pollution, and extensively more other issues – not only the anthropological. Humanity changed the Earth irreversibly, and we should take the responsibility to save our planet and protect the environment, which suffers so strongly. There is one concern which accompanies our life inherently – waste generation. Waste is an extensive problem, and its proper management should be the priority for everyone – for the better future for our generations.

1.1. Motivation

Growing demand for goods is caused by the unstoppable increasing number of people but also by growing level of life, escorted by – unintelligible to the author – race for the most potent argument of today's world – the money. The increasing growth of the industry, and hence the increase in the production of industrial goods which become sooner or later the waste, a growing number of multi-material waste – all this has a negative impact on the natural environment, and thus on human life and other living organisms. This phenomenon forces us to rationally manage waste so that as many as possible of it can be reused, and those that are not recyclable do not threaten the environment.

1.2. Topic Overview

Tires – which dominate the rubber market as no other product – are produced widely all over the world, and its production is growing every year. Those millions of tonnes of tires are a serious problem – they are very longlasting – unable to be degraded by the environment itself, and because they contain not only the rubber – along with other substances added to its structure – but also other materials – like steel and textile very difficult to recycle. Choosing the best solution fot managing the problem of tire waste can bring both – ecological and economic benefits. Nowadays there exist many practices to manage the problem of tire waste, but choosing the proper option depends on the end product we want to obtain.

1.3. Objectives

The objective of this thesis is to present a way of processing the rubber waste with steel cord – remnant left after tire production. The material that was tested was delivered by SUEZ Company, and is pre-vulcanised rubber waste with steel fascicle inside. Significant and difficulty feature of such waste material is its multi-material character – it consists of the rubber, but most of its mass is steel cord. Simultaneously those materials are widely used and could be reused in multiple processes. Additionally, rubber is material with high calorific value. There will also be presented methods and results of the tests conducted on the waste material delivered by the SUEZ Company. The primary process conducted was pyrolysis, and afterwards determining the elemental composition of remaining char – the gaseous parts were not the subject of the experiment.

1.4. Thesis Outline

This thesis is divided into two main parts – theoretical and practical part. Firstly it introduces with historical background of rubber and tire market, shows the main characteristics of tire and production process, perform the legislation background in relation to tire waste and presents various solutions for managing this issue – retreading and cutting the tread, usage of whole tires, granulate and reclaim preparation, thermal processing, also with energy recovery, alternative fuels from tires, usage in road constructions and other applications. Final part is practical one – it presents conducted laboratory tests which basis is pyrolysis, made on waste produced during the manufacturing of tires along with the results and conclusion.

2. Rubber and Tire Industry

World rubber consumption is rising every year and it is driven by unstoppable growth in motor vehicle production and world economy, which is getting stronger. Non-tire rubber will dominate and overtake tire rubber demand based on opportunities in the industrial, automotive, construction and consumer sectors.

2.1. Historical Background

The rubbes has its source in nature – it is made from the resin of the natural rubber plant. They firstly grew exclusively in the Brazilian rainforests, but thanks to English amateur botanist Jenry Wickham it got transported to United Kingdom and that resulted in growing seedling and setting up the plantations in Asia – the industry ceased to be dependent on Brasilian supply. With the time, rubber evolution promoted the displacement of this natural product from the market by its synthetic replacement - unsaturated hydrocarbons (e.g. butadiene or isoprene). Nowadays synthetic rubber is impossible to classify - there already exists hundreds of mixtures [12].

Pneumatic tire invented in second half of 19th century was modernized, and at the beginning of 20th century the tread was applied, a few years later the soot started to be added to the rubber mixture – tires changed color from grey to black. In the 20's J.B Dunlop developed the tire with steel and textile cord, which increased the resistance of the tires. Growing speed of trucks was the reason of fast heating up of the sides of tires, the remedy for that became invention of radial tires.

The following years brought development of tire specialization in the view of purpose, the possibility of retreading and the allocation on the axle [17].

2.2. Rubber and Tire Waste

Rubber is obtained from rubber producing plants with more than 90 % of all natural rubber production coming from Indonesia, Malay Peninsula and Sri Lanka. Synthetic rubber is produced similarly to plastics - by polymerization [1].

The rubber industry is well developed, complex and mature sector, with many different generic types of rubber, which are used in the production of various end products. The graphs in Figure 1 and Figure 2 show the natural and synthetic rubber consumption in key countries.

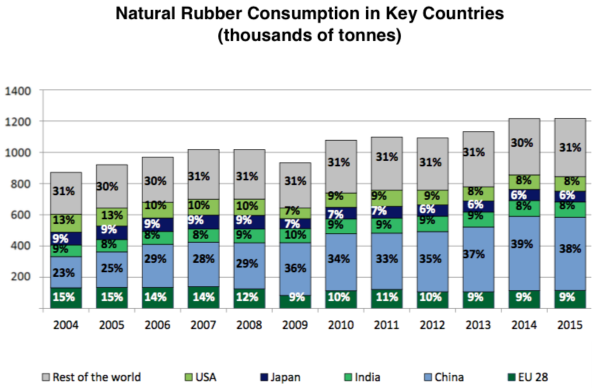

Figure 1: Natural rubber consumption in key countries [7].

Nevertheless, there is no single rubber product which dominates the rubber market as tires do. This is the reason for division in the rubber sector frequently used by analysts for two groups - the tire and the general rubber goods (GRG) sector. Consumption of rubber between those two sectors is approximately 50:50, where the transportation sector, in general, is estimated to account for 70 – 75 % of all rubber articles produced [8].

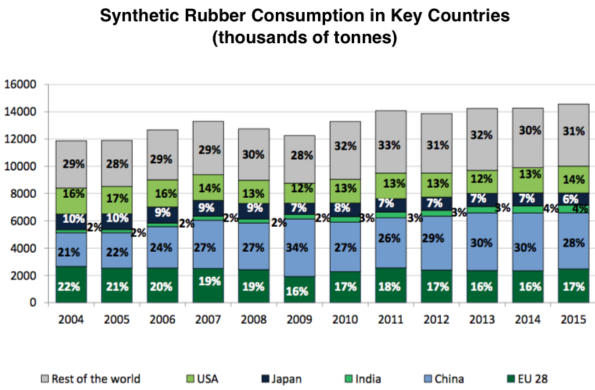

Figure 2: Synthetic rubber consumption in key countries [7].

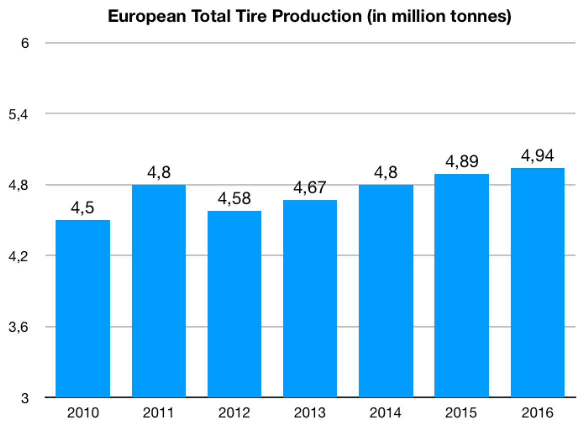

Figure 3: European total tire production in volume [14].

The graph in Figure 3 shows that manufacturing of tires in EU is growing, which is connected with the higher amount of waste – we can assume that every produced tire after some use finally becomes part-worn tire and then end of life tire.

Tires are manufactured from various ingredients – all types of tires regardless of the application are made from natural rubber with the addition of highly complicated synthetic mixtures of rubber with different ratios of those components and from its steel and textile reinforcement. The table shows the composition of car and truck tires.

Table 1 shows the composition of tires ingredients for car and truck.

Table 1: Car and truck tire composition [2].

Material	Car Tire [%]	Truck Tire [%]
Natural rubber	14	27
Synthetic rubber	27	14
Fillers (carbon black, silica)	26 – 28	26 – 28
Plasticizers (oil and resin)	5 – 6	5 – 6
Chemical additives (sulphur, etc.)	5 – 6	5 – 6
Metal for reinforcement	16,5	25
Textile for reinforcement	5,5	-

2.3. Tire Production Process

Tire production is a complicated process, divided into several stages. Every producer has its own techniques for producing tires. However, the overall process itself is similar for all the companies. Producers claim that tire consists of around 30 compounds, including rubber, textiles, steel cord and oily sub- stances. Production of tires process consist of six stages and it starts with the design stage. After designing and passing the tests positively the tire can start to be produced on the massive scale during the first stage of production The second stage of production refers to mixing all of the components. During the third stage, the elements of the raw tire are prepared – warp, bead, belt, tread, sides, rubber strips, liner, screen, and filler. Some of the rubber elements like tread, sides, and filler are obtained in the process of extrusion – forming the shape of those elements. In the fourth stage, the fabric and metal components are formed. During the fifth stage of production, the raw tire is finally formed. The process of forming is dependent on the producer's technology. The sixth stage is vulcanisation.

2.3.1 Vulcanisation

Vulcanization process is the transformation into the more bounded structure, which makes the material tougher and more resistant. During the process, the vulcanizing and accelerating agents are added to obtain the expected result. They modify the polymer by creating the crosslinks – bonds between particular polymer chains [11].

2.4. Basic Methods for Management of Used Tires

The rational approach to the recycling of used tires allows for the recovery of products, materials, and energy - which positively affects the natural environment and can bring also economic benefits. The very important aspect of managing of used tires are regulations, which indicate the correct and safe path of action. In this chapter, the basic methods of management of used tires will be described – regeneration, utilization, and recycling.

2.4.1 Retreading

Retreading of tires is a technology which allows recovering the primary properties of tires by placing a new layer of tread in place of the old, used one. At the end of the lifecycle of the tire, the depth of tread is lower than the EU limits. The tire can be utilized to preserve the structural features which makes it able to reuse the tire for the same purpose for which it was purposed, after a process called retreading [15].

2.4.2 Usage of Entire Tires

The usage of entire tires is a form of product recycling. This type of recycling is a form of direct reuse of product in good condition – not exploited very intensively. According to many scientists, it is the most profitable and simplest form of recycling – by reusing technically efficient parts, conditioned by their well technical condition. Tires are a great resource and their properties can not be underestimated: slow bacterial growth, very good resistance to smut, heat, moisture, sunlight, oils, acids and other chemicals. Furthermore, they possess with good elastic properties and resistance to physical impact. It does not require any material processing and allows for direct use of used tires [15].

2.4.3 Granulate Preparation

Actual process starts after "bead breaking" – the rubber part of tire is ground – the remaining flux is reduced into parts of different size, between 5 – 40 cm. They are called "slippers" and they consist of rubber, textile and metal fragments. The slippers can be utilized either for energy recovery, or reduced in size to separate the materials and make up the ELT. Such treatment of process is unfortunately rather expensive and requires a high amount of energy - around 125 kWh/tonne of tires. This presents a costly process, and there also has to be a business willing to purchase the granules [15, 1].

2.4.4 Reclaim Preparation

Reclaiming rubber from used tires is an appropriate approach to rubber recycling. The process itself is represents breaking of carbon bonds, while devulcanization means breaking of sulphurur bonds in the rubber molecular structure. Terms reclaiming and devulcanization are often interchanged. The process consists of exposing the rubber waste to the process of obtaining a plastic product, which can be mixed afresh with the components of rubber mixtures and re-vulcanized [2].

2.4.5 Thermal Processing

Tire waste is characterized by high calorific value, which suggests the thermal processes may be the suitable option for managing the problem – by the recovery of the energy content.

One of the most used thermal technology for managing the problem is the pyrolysis. Depending on the product we want to achieve in the end we should take into account, among others, size of the particles of the feedstock, the temperature of the process, reaction time, the speed of heating and atmospheric composition. By pyrolysis of tires we may obtain pyrolytic gas, oil or post-pyrolytic coal and steel [6].

Considering energy recovery – cement sector is the main one in Europe using ELT as TDF. European regulations permit for usage of ELT in cement plants and simultaneously limits its use and emissions connected with the process – it cannot exceed the 20 % of total fossil fuel required in the production of cement. They can be used as whole tires - without downsizing or processed in advance into pieces or powdered. Shredded tires can be also used in steel plant in electric arc furnaces as a substitution for anthracite. [10, 13].

3. Processing of Rubber Waste from Tires

Among the rubber waste, tires are indisputably the largest share. This kind of waste is one the one hand one of the most problematic sources of waste according to its size and multi-material character - they occupy a large amount of space and it the process of separation of the materials they are made from is rather complex. On the other hand, they are one of the most reusable waste – they can be successfully valorized and used for various purposes, by all means, according to the principles of sustainable solutions – reuse, recycling, recovery.

3.1. Cement Plant - Energy Recovery

Usage of waste tires in the clinker burning process seems to be the cheapest way of utilization of this type of waste, and what is more, it fulfils all the conditions for thermal utilization of waste. TDFs are used most frequently without any pre-treatment in the form of the whole tire, or after fragmentation in the form granulate. The are few reasons for using alternative fuels for this purpose: they are cheaper than carbon dust (or just carbon, and another expense for milling it), lower CO_2 emissions in comparison to carbon dust, lower emissions of thermal NO_x, lower emissions of harmful for environment gasses and ashes [9].

3.2. Product Recycling

Waste tires – pressed, cut or entire – find many applications in land and water construction sector, as a material for road surfaces, reinforcements of roadsides, sound barriers, protection of river banks, artificial reefs on the seabed, reservoirs and water channels in irrigation systems. More and more often it is used for upcycling – creative reuse. Another way of usage of used tires – particularly worn tires - is to cut the tread or retread process.

It is estimated, that around 15 – 20 % of worn tires are subjected to those processes, but those are applied mainly for truck tires [3].

3.3. Alternative Fuels

Concerning alternative fuels from rubber waste from tires, we distinguish two variants: used tires may be treated as the alternative fuel itself - as was described in chapters about energy recovery, or they may be used for the production of fuels (often previously separated from other tire materials).

The second variant can be achieved by PGL processes – pyrolysis, gasification, and liquefaction. Those are thermochemical processes through which carbonaceous feedstocks at elevated temperatures are transformed into usable products – electricity, chemicals, carbon black or fuels [16].

3.4. Usage in Road Construction

Car tires - in scraps or the whole - can be used in road engineering for various constructions such as embankments, ground reinforcements, road culverts retaining walls, and many more. Rubber granulate can be also used in asphalt surfaces [5].

3.5. Other Applications

Rubber from waste tires may be manufactured into many other general rubber goods, like gaskets, seals, anti-vibration mounts, tire treads, EPDM weatherstrips, industrial mats, carpet underlay, footwear, stationery, inks, recreational surfaces, and many others products.

4. Laboratory tests

Following part will be dedicated to the practical part of this thesis, which was conducted on the ground of Silesian University of Technology in Gliwice, Poland.

4.1. Examined Waste

The tested waste was received from the SUEZ company. It came in the form of big slices, which became glued together - the waste stripes were sticking tenderly yet - the rubber was not vulcanised yet. However, it had some specific smell, but it could not be described as characteristic rubber or tire smell - it was more chemical one.

As Figure 4 shows, inside the rubber layer there are bundles of metal - steel cord, they occur in two colors - silver or gold, depending on the slice. This waste was produced during the tire production, clearly, before tread was added - this material was the base for creating the tire.

To be able to conduct the laboratory tests, the size of waste had to be reduced, the pieces were sliced for smaller fragments - to fit into laboratory equipment. The metal part was very hard to break, it required quite a strength to cut it on the guillotine or by pliers, by hand. During cutting, the rubber layer was falling apart sometimes, and such pieces were not taken to the tests - I tried always to make pieces of rubber with steel cord.

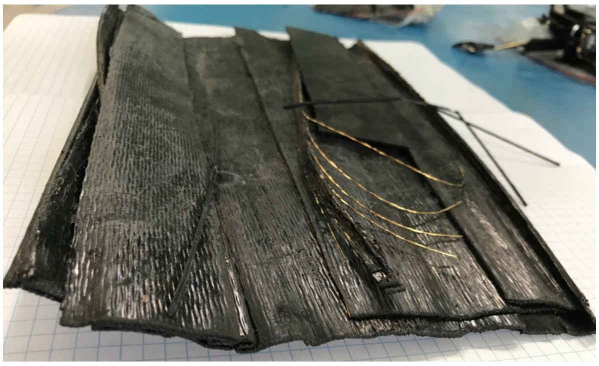

Figure 4: Examined waste from tire production process

The waste was firstly pyrolyzed in temperatures from 150°C to 600°C for every 50°C, 700°C, and 800°C. Then on every sample of char from each temperature, there were made further tests, along with the raw waste material - 13 samples, each for 2 trials, according to the rubber properties and the high temperatures in which samples were processed, the humidity in samples was assumed as zero.

4.2. Pyrolysis

The pyrolysis was made in the SUT laboratory on the outskirts of the city. The installation was not prepared for catching the gas from the process - it was coming out to the atmosphere, so the product for further tests was only the char.

The pyrolysis was conducted in the closed crucibles - without access of oxygen - in the electric stove. The crucibles with the waste were weighted, and then cold crucibles were placed in the stove preheated to the certain temperature. The time of residence of the crucibles varied for different temperatures - for temperatures 150 - 200°C - it was 30 minutes, then it was shortened to 20 minutes for 250 °C, then again for temperature 300 - 450°C it was shortened to 15 minutes, and finally, for the temperatures from 500 - 800°C the time of residence was 10 minutes. After that time, the crucibles were taken out on the ceramic plate to be cooled down to the temperature appropriate to place them in the desiccator, to reach the room temperature without access to any humidity. After that, the crucibles were weighted again. The procedure was repeated for the sample of every temperature applied.

To obtain the mass results, firstly the empty crucibles were weighted, then the examined waste was added and sample was again weighted, and finally, the sample was weighted after the process.

$$mce - mc = me \quad (1)$$

$$mce - mc = me \quad (2)$$

There was also calculated the loss of the mass after the process. Equation 3 was used.

$$\frac{100(me - mf)}{me} = \%L \quad (3)$$

There was examined the elemental composition of the waste – carbon, hydrogen, nitrogen, sulphur and chlorine content, the calorific value, volatile and combustible matter and the sieve analysis to asses the steel cord weight in the raw sample.Conducting further test was supported by a script for laboratory exercises [4].

The graph in Figure 5 shows the loss of mass obtained from the process of pyrolysis with different temperatures.

5. Results

The obtained results were recalculated with the respect to mass loss resultant during the pyrolysis process – to be able to see the overall results.

Table 2 shows the average results of all the calculations for each of the sample.

The heating value is decreasing along with the rise in temperature – which is connected with shrinking amount of the volatile matter with increase in applied temperature. Raw sample has its calorific value on the level of around 25 000 J/g, and after applying the 800°C during pyrolysis – the calorific value of char decreases to less than 10 000 J/g.

The carbon content in the samples is also decreasing with the rise in the applied pyrolysis temperature. The last sample, with 800°C applied during pyrolysis has the carbon content on the level of around 20 %, when the raw sample is almost 50 % of carbon content. The rapid drop begins at the point of 350°C - when the pyrolised rubber starts to be able to separate easily.

The hydrogen content in the samples are low - between 3,8 and 0,5 %, and it also decreases along with the temperature applied during the pyrolysis. The nitrogen content in the samples is similarly low – it varies between 0,6 and 1,9 %, and it also drops along the the temperature of pyrolysis. The sulphur content in the samples is very low – most of the obtained results are below 1 %. The potential decrease is also rather minor, about 0,5 %. The chlorine content in the samples is very low, all the results obtained are below 0,2 %. There is observable decrease in this element content along with the applied pyrolysis temperature, but it is not significant, especially according to the level obtained during the tests.

The volatile matter from the raw sample was 28,37 % and the combustible matter was 37,7 % and the combustible matter of the sample after the test for volatile parts was 11,85 %.

The sieve test result is that 94,77 % of the mass is steel cord and only 5,23 % is the ash from the pre-vulcanised rubber in the examined material. That means, that all of the results of the tested char from pyrolysis and raw sample were obtained from that nonsignificant part of mass – steel cord, which is substantial part of mass, always remained untouched, only in case of calorific bomb it got melted.

6. Conclusion

Tire waste is nowadays a severe problem - not only because of unstoppably growing production of this good all over the world - only in Europe from 4,5 mil. tonnes in 2010 to 4,94 mil. tonnes in 2016 but also because it contains various types of components, which is problematic in matters of its management. Especially, that tire itself is extremely durable - to be able to perform its primary function during usage - which is safe and effective connection between the vehicle and the surface, they are not biodegradable, and the components are joined in a hard to separate way. Luckily, tire waste is nowadays considered as a serious problem, and this is the reason for many restrictions concerning management of them. In EU there exist numerous regulatory frameworks concerning waste tires, including Waste Directive 2006/12/EC (75/442/EEC), European Waste List 2000/532/EC and amendments, Regulation (EC) No 1013/2006 on shipments of waste replacing Regulation No 259/93 1013/2006/EC (1.7.2007, Basel Convention transposition), Landfill Directive 1999/31/EC (26.4.1999) - banning tires on landfills,Directive on incineration of waste 2000/76/EC (4.12.2000) and Directive on End of Life Vehicles 2000/53/EC (18.9.2000). Base on the mentioned documents, European countries developed their own ELT management model - producers responsibility, tax system or free market system.

Tires are made from 3 main components - rubber, steel, and textiles. The rubber that tires are made of is a very complex mixture of numerous ingredients, such as natural and synthetic rubber, fillers - as carbon black and silica, plasticizers- oils and resin, chemical additives - sulphur and others - such structure with the tread ensures the excellent grip. The steel part with textiles are embed in the rubber mixtures, and such solution ensures not only the shape of the tire, but also makes it extremely tough and durable, and able to manage to lift the vehicle along with some load. By all means, there are also steel parts not embed in rubber -

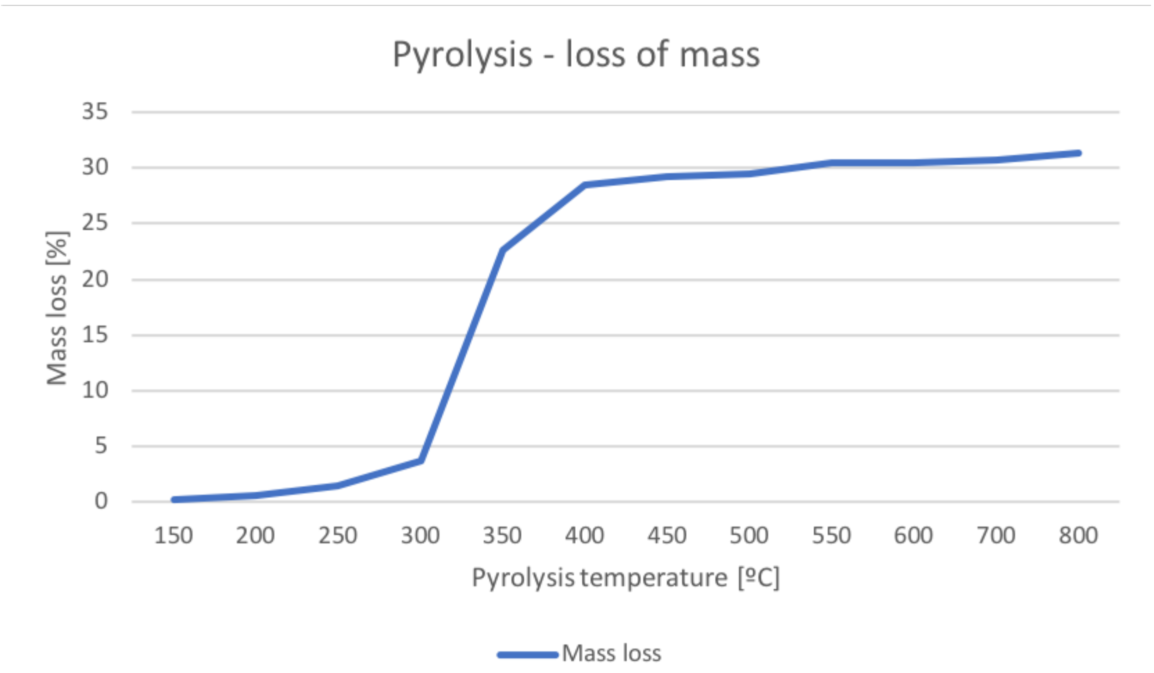

Figure 5: Loss of mass during of examined waste during pyrolysis

Table 2: Average results of all the calculations for each of the sample

T [°C]	m_e [g]	m_f [g]	m_e - m_f [g]	av. W_g [%]	av. C [%]	av. H [%]	av. N [%]	av. S [%]	av. Cl [%]	L [%]
analit. s.	-	-	-	23819	45,31	2,818	1,529	0,781	0,125	0
150	17,713	17,683	0,03	25831	47,635	1,84	1,887	1,037	0,126	0,169
200	19,235	19,116	0,119	23851	54,284	3,85	1,175	0,912	0,146	0,619
250	21,499	21,199	0,3	25287	52,203	2,791	1,329	1,027	0,163	1,395
300	19,93	19,206	0,724	22847	49,429	1,796	1,045	0,904	0,087	3,633
350	24,301	18,813	5,488	16549	46,794	1,201	1,071	0,971	0,058	22,583
400	22,993	16,445	6,548	12642	34,938	0,86	0,894	0,644	0,065	28,478
450	30,017	21,233	8,784	14804	35,633	2,36	1,416	0,779	0,172	29,263
500	21,009	14,81	6,199	15737	28,669	0,241	1,295	0,747	0,041	29,506
550	21,999	15,303	6,696	18249	38,902	0,679	1,325	0,939	0,112	30,438
600	27,533	19,137	8,396	17053	36,324	1,665	1,189	0,979	0,089	30,494
700	24,036	16,636	7,4	16449	34,178	1,312	1,078	0,993	0,196	30,787
800	27,043	18,556	8,487	14981	26,971	1,644	1,068	0,85	0,05	31,383

as an exemplary bead, but separating it from rubber part also requires the massive portion of energy. Those three main components separately are widely used in industry and may bring both - ecological as well as economic benefits - by saving the fossil fuels and using already existing ones.

There exist also something between the tire and waste tire - it is called a worn tire. This type of tire is already used to some level, but there exist techniques allowing using it as a good for a longer time. Such solution safe partly used tires to become the end of life tire and enables to make thousands of kilometers on the same product, without the need of buying new tires. Those techniques are retreading and cutting the tread. Retreading is covering the part worn tires with a fresh, brand new tread - it requires the carcass in excellent, untouched state to ensure the safety consistently. Cutting the tread is practically deepening it, removing the rubber layer under the original tread pattern which allows for restore optimal depths of the groove, which were lost during the usage. Unfortunately, according to the market situation nowadays it is not very widely used solution, especially speaking of the commercial vehicles. The price of tires makes it easier to lay in new ones, thank to experiment with some environmental friendly solutions. End of life tires - those impossible to reinstate to serve their primary function, may be reused in various types of solutions. They may be used as a whole, in many types of land and water constructions - road enforcements, breakwaters and erosion barriers artificial reefs, insulation of construction barriers, sound absorbing barriers, irrigation systems membranes, and drainage layers and many others. More and more popular is upcycling of waste tires - using them as a part of garden or playground or just some piece of art, after remaking its appearance into one which pleases the eye. Tires as a whole might also be used as a fuel - exemplary in cement or steel plants - they are characterized by a relatively high calorific value. Then that problematic multi-material character might be recognized as an advantage - metals present in tires might improve the characteristics of clinker, and in steel plant - it might also improve the metallurgical performance of the product. Such solution results in saving the fossil and other fuels - by reusing waste for such purposes.

Waste tires can also be used for another tire-derived fuels or byproducts. It is possible to create granulate - of different diameter - which is rubber material further used as an additive for producing other products - like mats, bumper liners, car floors, heels, sandals, soles. It may also be additive for producing the asphalt mixtures and other road surfaces. Another byproduct possible to produce from waste tires is the preparation of reclaim - ductile product with properties similar to caoutchouc. It might be reused for production of tires, anti-corrosion agents, road surfaces and many others.

Already mentioned high calorific value of waste tires give rise for using it for energy recovery and for forming alternative fuels and chemicals. That brings for discussion PGL processes - pyrolysis, gasification, and liquefaction. Pyrolysis, which is, in the beginning, an endothermic process conducted without access of oxygen in the temperature typically exceeding 400°C and thereby requires an external source of energy to initiate the process. Its products are pyrolytic gas and char, which may be subject for producing further goods, like carbon black and silica. Gasification, which is operated in the partial oxidative environment in the elevated temperatures - commonly 700 - 800°C - produces the useful gas called syngas, which after further treatment may be used for the production of various fuels - like pure hydrogen and methanol or synthetic gas or gasoline. Those may be used for various purposes - to produce heat or electricity on as a fuel for vehicles. Liquefaction is a thermal process of converting the solid rubber material into liquid form. It occurs in the lower temperature range than pyrolysis and gasification. It may be successfully used for separation of the rubber, steel and textile components of the tire.

Most of the mentioned solutions for the managing problem of tire waste - those which do not use tires as a whole - generally require pretreatment in the form of separation the main compounds of the tire. Apart from liquefaction there are used grinding methods: mechanical, cryogenic, wet, water jet and Bersdoff. They all have their advantages and disadvantages in the form of the size and condition of rubber and additional expenditures for various processes - like freezing with liquid nitrogen or drying the material. Grinding the waste material allows the steel and textile part to be removed by separators.

To choose the most suitable way of managing the problem of waste from tires there is a need for the future plan for its usage. Processing of this material is extremely costly regarding energy that must be delivered for conducting any procedure, and so it is rather expensive, not only in terms of finances but also potential fuels used for electricity or heat generation further used in the treatment. Exemplary - the granulate is produced only for an order of probable client - there probably do not exist any reserves of such byproduct.

Examined waste is the waste produced during the tire production process. It does not remain the tire shape - the rubber is pre-vulcanised yet, and the waste is in the form of rubberized steel cord. The rubber itself is quite elastic but fragile simultaneously, but the steel cord makes this material very tough and hard to damage. The fragments of such material were cut for smaller parts to be easily transported to the laboratory, and for tests, it had to be cut for tinier parts - to fit the laboratory equipment.

The pyrolysis which was base of the tests conducted on that waste was the idea for the separation of those materials. The breaking point of the test was the temperature of 350°C applied for pyrolysis when the steel cord started to be easily separated from the powdered rubber. Nevertheless, the cord was always covered with particles of rubber dust.

This material was quite problematic concerning preparing the samples - the steel cord is characterized by high mechanical durability, and the rubber was fragile and often got departed from the steel material. That is the reason for obtaining such imperfect for first sight results. However, those shows the trends occurring after the conduction of the pyrolysis clearly. All of the examined components of elemental composition were decreasing along with the rise in the temperature applied during the pyrolysis, even if its content was low in the analytical sample. Calorific value was similarly reduced along with the rise in the temperature applied during pyrolysis. Nonetheless, calorific value of analytical sample and samples up to temperature of 300°C were higher than 20000 J/g, which might be recognized as high value, especially according to the fact, that the steel cord was major part of the sample's mass - sieve analysis demonstrated that more than 95% of mass of combusted analytical sample is cord, and only less than 5% was ash from rubber.

Unfortunately, it is impossible to reach the information about how much of such waste is generated during tires production, those numbers probably vary depending on technology applied by the manufacturer. Depending on the amount of waste, there could be designed a particular way of managing this problem. Nonetheless, the proceeding should take into account the all types of expenditures - not only the financial but also energetic or environmental ones.

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