Impurities analysis in ELT products deriving from mechanical recycling

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Abstract

Mechanical treatment for End of Life Tyres (ELT) leads to the production of materials for recycling or reusing, and is more preferable in terms of waste treatment hierarchy compared to ELT energy valorisation. There have been plenty of works on the physicochemical characteristics of the products from ELT mechanical recycling, however there is not any available literature regarding the products' purity in Greece. The present work, focuses on the analysis of the main flows of ELT mechanical recycling (rubber, textile, steel wire) in impurities which derive from contamination from other streams of ELT recycling, for four plants located all over Greece. Sampling and analysis was carried out in three months period according to CEN/TS 14243:2010. The analyses conducted include particle size distribution, magnet separation and hand-separation for the determination of impurities e.g. percentage of textile and steel wire present in crumb rubber. It was found that rubber is the most clean of the products with purity of 99.99% in most cases. Moreover, textile contained no wire while the concentration in rubber powder varied from 7% to 35% depending on the plant. Furthermore, steel wire contained both rubber and textile streams, presenting on average 2.7% in rubber and 0.81% in textile, with an exception which reached about 27% as total contaminants. Concluding, rubber which is the main product of the recycling activity is of high quality, while there can be improvements for the remaining two streams.

Keywords

End of Life Tyres, Mechanical Recycling, Materials Recovery, Impurities

1. Introduction

During the last decade, there is a continuously increasing number of Tyres that are discarded as reaching their end-of life cycle. The methods utilized for treating the used and end-of-life tyres (ELT), lean towards more environmental friendly solutions such as recycling and energy recovery. More specifically, in 2015, more than 2.8 million tons of ELT were managed in EU28 [1], which led the utilization of 1.612 kt for material recovery and 1.022 kt for energy recovery. Regarding material recovery, 112kt where used in civil engineering works while 1299kt where sent for granulation, 11kt used in steel mills and foundries, 41 kt used as dock fenders/ blasting mats, and 24 kt used in pyrolysis.

As far as EU is concerned, according to ETRMA [2], recycling (granulation) is becoming a continuously favourable ELT management scheme compared to energy recovery. What is more, the past 20 years, recycling has increased its share in ELT management from 13% to 35%, while energy recovery dropped from 53% to 37%.

In Greece, material recovery accounts for around 47% of ELT treatment, according to the recent data collected and published by the Greek organization ECOELASTIKA which is responsible for ELT collection and management. More specifically, as it is presented in *Figure 1*, the latter years, recycling has been gaining ground in comparison to energy recovery, reaching up to 60% for 2016.

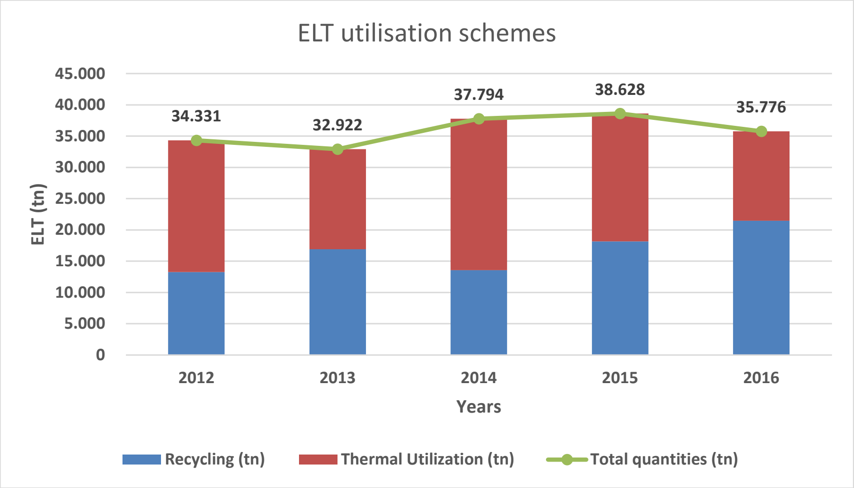

Fig. 1 ELT utilisation schemes and quantities in Greece per type of scheme

Processing of ELTs takes place in specialized units [3], which through a series of mechanical processes including shredding (TDF production) and granulation followed by gravimetric separations; produce rubber crumb, textile and wire as is shown in Figure *2*.

Fig. 2 ELT composition

Materials deriving from ELT recycling, find use in many applications ranging between utilization in synthetic turf [1], road asphalt mixtures [4, 5], sound absorption [6], use of granulates in membrane production [7], other materials [8] and virgin material production [9]. In all of the aforementioned applications, the quality and pureness of the utilized recovered material, plays a major role in the application process and final product quality. E.g large amounts of rubber crumb impurities in textile produced, result in material failure for woven materials utilizing ELT textile.

The presented work focuses on the sampling and analysis of Greek ELT mechanical separation products (rubber crumb, textile and wire), which are intended for further use. The samples are received from four different recycling plants, one located in Drama Region, one located in Larisa Region, one located in Attica Region and the last one located in Achaia Region. This selection was made in order to have a more representative depiction of composition of tyre recycling products utilized throughout Greece.

Sampling and analysis was conducted on rubber crumb, textile and steel wire, and include the determination of impurities in each of the product. More specifically, it was carried out according to standard EN 14243: 2013 on “Specification of categories based on their dimension(s) and impurities and methods for determining their dimension(s) and impurities”. The novelty of this work, lies on the following two targets. Firstly, the quality of Greek products was determined, a work which has not been elaborated before, and secondly the potential of mechanical separation technology was tested in terms of material recovery

2. Methods

A brief and concentrated work diagram is presented in Figure 3. Mechanical treatment plant A is located in Attica region, plant B in Achaia region, plant C in Drama region and plant D in Larisa region.

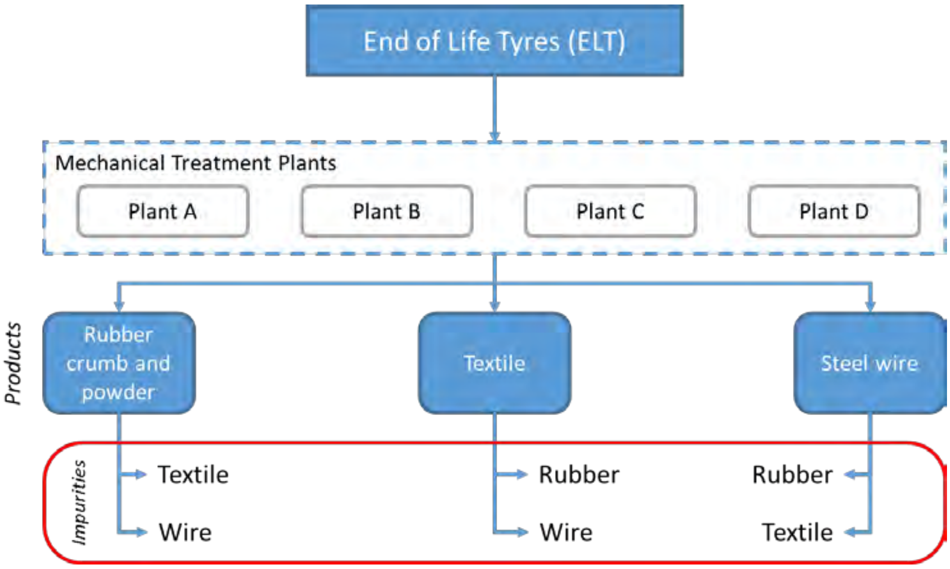

Fig. 3 Flowchart of present study

2.1. Sampling procedure

The sampling procedure was designed and implemented according the CEN/TS 14243:2010 [10]. Samples were gathered for all products of each of the aforementioned plants and were received either from permanent or temporary storage, following a specific procedure by gathering sub-samples from different random places which composed a representative sample. As was mentioned before, the chosen plants are located in different regions of Greece, in order to receive results which could be representative for all Greece. For the definition of sampling lot, the monthly production was taken into consideration in order to have an even more representative sample. As it is obvious, the produced quantities are divided in all of the particle size dimensions produced from a plant. Once again, the produced amounts taken in consideration are applied to each granulometry in consideration. As far as the sub-sample quantities are concerned, for rubber crumb the minimum sub-sample size is 500ml, for textile it is 0.2

kg and for steel wire it is 0.5 kg. In the following table (***Table 1***), the number of samples, sub-samples, as well as the quantity for each sample per mechanical treatment plant are given.

Table 1: Number of samples gathered for each product/by-product and mechanical plant

	Plant A	**Plant B**	**Plant C**	**Plant D**
Rubber crumb / powder	2 samples / 7 sub-samples and 3.5 lt each	3 samples / 12 sub-samples and 6 lt each	3 samples / 14 sub-samples and 7 lt each	3 samples / 12 sub-samples and 6 lt each
Textile	1 sample / 6 sub-samples total 1.2 kg	1 sample / 5 sub-samples total 1.0 kg	1 sample / 5 sub-samples total 1.0 kg	1 sample / 5 sub-samples total 1.0 kg
Steel wire	1 sample / 5 sub-samples total 2.5 kg	1 sample / 6 sub-samples total 3 kg	1 sample / 5 sub-samples total 2.5 kg	1 sample / 6 sub-samples total 3 kg

In ***Figure 4***, pictures from sampling of tyre crumb, steel wire and textile are given. All of them are gathered from temporary storage piles created from the free flowing material as produced after the mechanical separation.

Fig. 4 Samples gathering

2.2. Analyses

The gathered samples underwent analysis in order to specify the impurities content. Namely, the following were specified according to CEN/TS 14243:2010 [10].

- Textile and steel wire content in rubber crumb
- Rubber crumb and steel wire content in textile
- Rubber crumb and textile content in steel wire

The separation of textile from rubber crumb and powder was carried out by sieving, following the method of “small ball agglomeration” and the instructions of technical specification 14243:2010 [10]. The sieves used are in line with standard ISO 3310-1:2010 [11], while the sizes used are 0.25, 0.5, 0.8, 1, 2, 3.15, 4.75, 6.3 mm. The total sample analyzed for every size distribution, was 1kg. Separation of steel wire from rubber crumb and powder was done with the use of a magnet of certain dimensions and a magnetic density of over 1T. The separation of rubber crumb/powder from textile was carried out by sieving, while the separation of steel was carried out by the use of magnet. The sizes of sieves used for separation of rubber powder from textile were 0.25, 0.5, 0.8 and 1 mm.

In order to classify the impurities found in the produced steel wire, the samples underwent manual separation, for the division in steel, textile and rubber. In figure 5, agglomerations of rubber and steel wire which were found in the sample and could not be easily separated with mere shaking, are presented. This fraction was separately weighted and then forcefully (where possible) separated, and each of the component was added to the respective quantities already found.

Fig. 5 Agglomerations of rubber and steel wire

3. Results and Discussion

In the following four tables (***Table 2*** - **Table 5**), the sieving analyses are presented for the four mechanical treatment plants, presenting the textile impurities in rubber.

Table 2 Plant A textile impurities in rubber crumb and powder

Crumb 0.5 – 1.5 mm			**Crumb 0.5 – 2.5 mm**		
Sieves	% Rubber	% Textile	Sieves	% Rubber	% Textile
>3.15 mm	4.1 %	-	>3.15 mm	11.8 %	-
3.15-2.00 mm	46.3 %	-	3.15-2.00 mm	56.4 %	-
2.00-1.00 mm	47.9 %	-	2.00-1.00 mm	31.1 %	-
1000-800 μm	1.5 %	-	1000-800 μm	0.4 %	-

Crumb 0.5 – 1.5 mm			Crumb 0.5 – 2.5 mm		
Sieves	% Rubber	% Textile	Sieves	% Rubber	% Textile
800-500 µm	0.2 %	-	800-500 µm	0.0 %	-
<500 - 250µm	0.0 %	-	<500 - 250µm	0.0 %	-
<250µm	0.1 %	-	<250µm	0.1	-
Total	100 %	-	Total	100 %	-

Table 3 Plant B textile impurities in rubber crumb and powder

Powder <0.8mm			Crumb 0.8 – 2.5 mm			Crumb 2.5 – 4.2 mm		
Sieves	% Rubber	% Textile	Sieves	% Rubber	% Textile	Sieves	% Rubber	% Textile
>1000 µm	0.1 %	-	>3.15 mm	>0.1 %	-	>6.30 mm	-	-
1000-800 µm	0.2 %	-	3.15-2.00 mm	7.5 %	-	6.30-4.75 mm	-	-
800-500 µm	16.6 %	-	2.00-1.00 mm	58.8 %	-	4.75-3.15 mm	60.8 %	-
500-250 µm	54.1 %	-	1000-800 µm	11.0 %	-	3.15-2.00 mm	33.0 %	-
<500 µm	29.1 %	-	800-500 µm	14.7 %	-	<2.00 mm	6.3 %	-
			<500 µm	7.9 %				
Total	100 %	-	Total	100 %	-	Total	100 %	-

Table 4 Plant C textile impurities in rubber crumb and powder

Powder <0.8mm			Crumb 0.8 – 2mm			Crumb 2 – 4mm		
Sieves	% Rubber	% Textile	Sieves	% Rubber	% Textile	Sieves	% Rubber	% Textile
>1000 µm	1.3 %	-	>3.15 mm	>0.1 %	-	>6.30 mm	-	-
1000-800 µm	10.7 %	-	3.15-2.00 mm	6.4 %	-	6.30-4.75 mm	-	-
800-500 µm	42.1 %	-	2.00-1.00 mm	78.3 %	-	4.75-3.15 mm	83.2 %	-
500-250 µm	37.0 %	-	1000-800 µm	12.5 %	-	3.15-2.00 mm	15.4 %	-
<500 µm	9.0 %	-	800-500 µm	2.6 %	-	<2.00 mm	1.4 %	-
			<500 µm	0.2 %				
Total	100 %	-	Total	100 %	-	Total	100 %	-

Table 5 Plant D textile impurities in rubber crumb and powder

Powder <0.8mm			Crumb 1 – 3 mm			Crumb 2 – 4 mm		
Sieves	% Rubber	% Textile	Sieves	% Rubber	% Textile	Sieves	% Rubber	% Textile
>1000 µm	0.1 %	0.7%	>3.15 mm	14.2 %	-	>6.30 mm	-	-
1000-800 µm	1 %	-	3.15-2.00 mm	35.9 %	-	6.30-4.75 mm	-	-
800-500 µm	37.8 %	0.1%	2.00-1.00 mm	38.3 %	-	4.75-3.15 mm	86.7 %	-
500-250 µm	43.4 %	0.3%	1000-800 µm	5.7 %	-	3.15-2.00 mm	12.6 %	-
<500 µm	16.7 %	-	<800 µm	5.9 %	-	<2.00 mm	0.7 %	-
Total	98.9 %	1.1%	Total	100 %	-	Total	100 %	-

In the samples taken by Plant A, negligible quantities of textile (<0.1%) with granulometry <250μm were found. Interestingly, the sample which has a particle size range of 0.5 - 1.5mm, contains about 50% of the crumb, in granules higher than the samples' nominal diameter produced. Correspondingly, the produced 0.5-2.5mm crumb rubber has at least 11.8% of a higher particle size gradient than the specified one. Regarding Plant B, in the powder (<0.8 mm) negligible quantities of textile (<0.1%) were found. The same was observed for granulometry of 0.8 – 2.5 mm, while in the fraction 2.5 – 4.2 mm, no textile was found through sieving. A note regarding particle size distribution is that about 23% of the quantity lies below the lower margin for the fraction 0.8 - 2.5mm whereas this percentage is 6.3% for the fraction 2.5 - 4.2mm. In the produced fractions of plant C, also no textile was found. However, we observe that the smaller the product diameter is, the higher the percentage of granules outside the specified limits are.

In plant D, textile was found only in the produced rubber powder (<0.8 mm), which is equal to 1.1% of the sample. From the amount of textile found in the fraction <0.8mm, the largest percentage was found in particle size above the production specifications.

In **Table 6**, the steel wire content in the analysed samples is given. The separated amounts of metal also include the rubber crumb which is agglomerated with them, as specified in the followed standard. For that reason, it is observed that in some cases, at larger particle size fractions, a larger percentage of metal is found (since the larger the particle, the heavier it is). However, what is observed is that all plants have impurities of 0.01% and below. An exception is Plant C samples, with the particle size fractions 0.8 - 2 mm and 2 - 4 mm exhibiting 0.03% and 0.09% wire concentrations, which can be considered as negligible. Similarly, Plant B presented 0.02% for granulometry of <0.8mm and 2.5-4mm.

Table 6 Steel wire content in samples received

	Granulometry	Rubber content (% wt)	Steel wire content (% wt)
PLANT A	0.5 – 1.5 mm	99.99 %	0.01 %
	0.5 – 2.5 mm	99.99 %	0.01 %
PLANT B	<0.8 mm	99.98 %	0.02 %
	0.8-2.5 mm	99.99 %	0.01 %
	2.5-4.0 mm	99.98 %	0.02 %
PLANT C	<0.8 mm	99.99 %	0.01 %
	0.8-2.0 mm	99.97 %	0.03 %
	2.0-4.0 mm	99.91 %	0.09 %
PLANT D	<0.8 mm	99.99 %	0.01 %
	1.0-3.0 mm	99.99 %	0.01 %
	2.0-4.0 mm	99.99 %	0.01 %

In ***Table 7***, the concentrations of rubber and textile impurities in the produced steel wire are presented. From the analysis results, plants A, B and C present impurities which do not deviate much among each other, and fluctuate between 2.5% and 4.7%. In plant A and plant C, it is observed that the majority of impurities derive not from the free material, but from the agglomerations that are broken down. On the other hand, plant D presents impurities of a total 27.8%, most of which derive from the not agglomerated material.

What is more, comparing all of the impurities percentages, it is seen that the largest percentage is contributed by rubber. More specifically, more than 70% of impurities mass is attributed to rubber, either as an agglomeration or as free material in produced steel wire.

Table 7 Analyses of steel wire in rubber and textile impurities

	Plant A	**Plant B**	**Plant C**	**Plant D**
Agglomerate (% wt.)	4.87%	1.68%	2.84%	17.39%
Wire (% wt.)	*2.85%*	*0.76%*	*1.34%*	*5.22%*
Rubber (% wt.)	*2.02%*	*0.92%*	*1.50%*	*12.17%*
Steel Wire total (% wt.)	96.83%	95.28%	97.37%	72.22%
Textile total (% wt.)	0.49%	1.52%	0.43%	6.09%
Rubber Total (% wt.)	2.68%	3.21%	2.20%	21.70%
TOTAL impurities (% wt.)	**3.17%**	**4.72%**	**2.63%**	**27.78%**

In ***Table 8***, the rubber concentration in the produced textile in each plant is presented. The results show that the purest textile is produced by plants D and B, with a concentration of elastomer powder at 7 and 9.2%, respectively. Plants C and A contain rubber at significantly higher percentages than the other two plants, rising up to a rubber concentration of 21.7% and 35.3%, respectively. This presents that plants C and A, either lack a separation step or a process mode, which could not only provide cleaner textile, but also increase the rubber amounts produced.

Table 8: Rubber impurities in the produced textile

	Plant A		**Plant B**		**Plant C**		**Plant D**	
	% Rubber	% Textile	% Rubber	% Textile	% Rubber	% Textile	% Rubber	% Textile
>1000 µm	11.8 %	64.6 %	0.5 %	90.5 %	7.5 %	77.7 %	3.6 %	92.6 %
1000-800 µm	6.3 %	-	0.3 %	-	1.4 %	>0.1 %	0.7 %	-
800-500 µm	7.9 %	-	1.2 %	-	4.1 %	-	0.7 %	-
500-250 µm	5.7 %	0.1 %	3.5 5	0.3 %	3.5 %	0.2 %	0.6 %	-
<250 µm	3.6 %	-	3.6 %	-	5.2 %	0.4 %	1.5 %	0.4 %
Total	**35.3 %**	**64.7 %**	**9.2 %**	**90.8 %**	**21.7 %**	**78.3 %**	**7.0 %**	**93.0 %**

4. Conclusions

In the framework of the present work, samples from ELT mechanical recycling process where gathered and analyzed in order to determine the impurities content in each of the produced fraction. Sampling and analysis was carried out in accordance to CEN/TS 14243:2010, where a total of 14 rubber, 4 textile and 4 steel wire samples were obtained. Specifically, the analysis determined a) textile and steel content in produced rubber, b) textile and rubber content in steel wire, and c) rubber and steel content in textile.

In the rubber samples analyzed, there was no textile concentration found, with the exception of the smallest particle size produced by plant D, where textile concentration of 1.1% was found. In addition, in all rubber samples, wire concentration was less than 0.01%. Exceptions are two samples of plant B with a concentration of

0.02% and two samples of plant C with a 0.8 - 2 mm and 2 - 4 mm particle size which exhibited 0.03% and 0.09% wire concentrations respectively.

In wire samples, plants A, B and C show impurities ranging from 2.5 to 4.5%. The highest impurities were presented by plant D with 27.5%, of which 21.7% is elastomer. In textile samples, it is shown that the purest product is produced by the plant D and plant B companies, with a concentration of rubber powder at 7 and 9.2%, respectively. Plant C and plant A produce textile with an elastomer concentration of 21.7% and 35.3%, respectively.

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