METHOD AND INSTALLATION FOR RECYCLING PLASTIC WASTE AND TONER DUST IN THE PRODUCTION OF ASPHALT MIXTURES

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Abstract: The waste management represents a significant issue worldwide that can be turned into an excellent opportunity for using the waste as raw materials in the processing industry, partially replacing the raw materials originated from natural resources. Plastic materials are products obtained almost entirely of petrol, and become a critical material in the modern world, being used for producing consumer goods in engineering or in constructions. It is strong, but this resilience makes it dangerous for the environment and thus, for people. Toner is used throughout campus in photocopiers and laser printers. The waste toner powder recycling presented a problem due to its complicated composition. This paper proposes changing of some current installations for producing asphalt mixtures and adapting it to the proposed technology for recycling the plastic waste and toner dust during the production processes of the asphalt mixtures.

Key words: waste plastic, Asphalt mixture, waste toner dust, road construction, recycling.

1. INTRODUCTION

On average, each of the 500 million people living in the European Union annually disposes around a half ton of household waste. In addition to this waste, standard quantities of waste generated from daily activities are accumulating, i.e. processing industry (360 million tons) and constructions (900 million tons), while the water and power supply generates other 95 million tons. In total, the European Union annually produces up to 3 billion tons of waste. Plastic is a synthetic material non-biodegradable, suffering a photo-degradation process, being transformed in small plastic pieces (micro-particles). These are still plastic polymers, and even this decay process can take a long time, i.e. a plastic casing can photo-decay under the sun action in over 500 years. Plastic is a relatively new material, introduced in the industrial production only in 1907. The global plastic production has increased from 1.5 million tons (Mt) / year in 1950, to 245 million tons in 2008, out of which 60 million tons only in Europe. The production of the past ten years equaled the production registered during the entire 20th century. It is estimated (in a status quo scenario) that 66.5 Mt of plastic will be introduced on the EU market till 2020 and that the global plastic production could triple before 2050.

The plastic production in the European Union (EU-27 + 2) in 2012 amounted 20.4% of the total world production of plastic. China remains the leader on the market with a plastic production of 23.9%, and rest of Asia (including Japan) accounts 20.7% [1]. According to the law, there are strategic elements approaching the issue of plastic waste from the environment. The framework directive regarding the wastes (2008/98/EC) is focused on such elements as the lifetime of the products, waste generation prevention, as a priority regarding their treatment, extended responsibility of the manufacturers, products design as to be environmental “friendly”, power efficiency and resources preservation.

However, there is a strong contrast between the legislation requirements and the actual practices when managing the wastes thus, in 2012 the percentage of recycled plastic waste in the EU member states was of 26.3 %, and the percentage of those energy-exploited 35.6. Unfortunately, although plastic waste is recyclable, a percentage of 38.1 % was eliminated through storage [1]. The empty cartridges are waste originated from using the consumables of IT and office equipment. They are considered WEEE if they are handed over together with the worn equipment. A part of used cartridges can be used again (following a technological regeneration process), obtaining so a new product of high quality, at a lower price.

Legally, the wastes originated from the electric and electronic equipment (WEEE), are regulated on the national level in the Government Decision No. 1037/2010, and in Europe in the EU Directive No. 2002/96/EC (known as WEEE). This aims to prevent producing the wastes originated from electric and electronic equipment (WEEE), and encourage the reuse, recycle and exploit them in various forms.
2. LITERATURE REVIEW

A used toner cartridge, in most case, is eliminated without being recycled. In the best case only the casing (the cartridge) is reused. Although the latter option is recommended, the cartridge can be reused by a number of times, and the cartridge is eventually eliminated. For avoiding the cartridges waste, there various technologies that were developed in time for recycling them. The cartridge contains metals, plastic materials and toner dust. The empty cartridges are never completely empty, and before being refilled, the cartridges shall be cleaned from the residual toner dust. The toner dust is absorbed by the components of the cartridge through various types of dust suction systems. Some of these can be very small units or important industrial installations. The collecting units in vacuum are collecting the dust in special recipients. These recipients contain tens of different types of dust, as the manufacturers use different types of toner dust. All these factors result in very difficult dust exploitation.

The toner dust is made of polymer particles, carbon black and metallic oxide, a very fine dust that can be dangerous for the people’s health if inhaled in large quantities.

Currently, the most common recycling method for toner cartridges is eliminating the residual toner, dismantling/grinding the cartridges and then sorting the resulted materials based on categories. The recovered materials categories are: plastic materials, steel and aluminum, and some quantities of other several types of metal and plastic. The separation and grinding operations can be totally manual up to entirely automatic. If the processes are carried out correctly, and the separated materials fulfill the quality conditions to be exploited, they can be sold for prices that can compensate a significant part of the recycling operation costs.

Ruan J. introduces a mechanical recycling technology for the toner cartridges, environmentally friendly, including a grinding process, a magnetic separation, and an eddy wind separation. The recovery rates of the ferrous metals (magnetically separated), the toner dust, the aluminum and plastic are 98.4%, 95%, 97.5%, and 98.8%. Cartridges are grinded, the dust is aspirated, and the other materials are subsequently going under a magnetic separation process. The obtained dust is solidified through a clean, thermal aggregation process. The described aggregation process uses the feature of thermic solidification of the toners dust. Thus, this becomes sticky and bounded at a low temperature, i.e. less than 1 500 F [3].

A sure method for recycling the toner cartridges, which avoids the handling of the fully dry toner dust is introduced in the USA’s Patent No. 7999012/16.08.2011. The toner cartridges are processed in a non-inflammable liquid environment. This method captures most part of the toner dust in the fluid within the process. The fluid is then filtered and reintroduced into the process [2].

The technological flow chosen by us for recycling the toner waste includes following phases:

1. collecting, manual sorting; the cartridges that have not suffered mechanical impacts and can be reused are separately stored;
2. dust suction from the cartridges components;
3. cartridges grinding;
4. magnetic separation of the ferrous part;
5. separation with eddy wind of the other parts, i.e. plastic and aluminum.

Regarding the efficient usage of the resources, it is very important to avoid waste reaching the wastes storages. The wastes storage is a waste of resources that should be avoided in favor of recycling. Ideally, all wastes should be able to be recycled with reasonable costs and in an environmental friendly, and therefore people-friendly manner.

Thus, it would be stimulating if wastes of plastic materials and dust originated from recycling the toner waste can be reused in the production of asphalt mixtures for paving, as a useful material, for improving the lifetime of the road paving on one hand, and preventing the environment pollution on the other hand.

Currently, there are studies evidencing that by introducing a plastic waste and a toner waste in the production recipe of the asphalt mixtures, their quality is superior to that of the standard mixtures. There are various studies that analyzed the quality of the asphalt obtained with introducing plastic waste in the production process and other studies that analyzed the possibility of using the toner waste in producing the asphalt mixtures, and in both cases, the results were positive.

In well-known technical solutions, the issue of the methods and installations for recycling the plastic waste and toner dust, within the same technological process, is not approached.

The asphalt is a mixture of bitumen and mineral aggregates, used for roads construction. Based on the usage domain, the asphalt contains 5–10 % bitumen, the difference among them being the grinded rocks (90–95%). For improving the asphalt characteristics, filler, sand or fibers can be added. The bitumen mixture and mineral aggregates are known as natural asphalt.

The bitumen is a product with high viscosity, high-boiling, with a dark color, obtained as a residue of crude oil processing.

The bitumen modified with polymers is a binder with plastic material added to its composition. This significantly improves the characteristics of bitumen. The modified bitumen is specially created to be used in the high traffic roads constructions. Its importance is continuously growing.

A research project carried out by the Transport Department in Texas and Austin University in Texas, investigated the feasibility and potential benefits of using the residual toner dust in the obtaining method of the asphalt mixtures, concluding that the toner waste can be successfully used in the asphalt mixtures, improving the characteristics of binder, of the bitumen respectively, the study recommendations being:
1. To obtain a homogenous mixture, it is necessary to combine the toner dust waste with bitumen for about two hours, at a temperature over the melting point of the toner dust waste. If the mixing speed is very high, the period can be reduced up to 20–30 minutes.

2. The material is not stable when stored, it must be stirred before being mixed with the aggregate.

3. The viscosity of the binder increases with the added toner dust quantity increase.

4. The resilience at high and average temperatures increases with the added dust quantity increase.

5. The rigidity of the material increases with the added dust quantity increase.

6. The added toner dust percentage shall be between 6 and 8%, based on the bitumen and aggregate contents. The toner dust can be added directly into the aggregate or bitumen, the recommended and used solution being to add dust directly into the bitumen [6].

In 2000, Tripathi et al. obtained a license stating that the toner dust is a material recommended to be used in asphalt mixtures, having in view its composition (styrene-acrylate copolymer and carbon black), its shape as powder. Due to lack of exploiting solutions, this will have a low price and a large available quantity on the market. For many applications, a toner content of about 5% to 10% ensures a better balance of characteristics, i.e. between rigidity and viscosity on one hand, and resilience, stability and sensitivity at temperature on the other hand. As stated in the license, adding a mass percentage of 20% of toner dust from the asphalt mixture will result in a very satisfying efficiency of the product quality obtained for paving the roads. Tripathi et al. recommends that the toner dust be mixed directly with the bitumen, a dry method, before adding the aggregate, the toner and bitumen shall be stirred at a temperature with at least 10 °C over the melting point of the toner dust, usually at about 100–150 °C. The best results are obtained when the mixing temperature is maintained at about over 165 °C. Tripathi et al. believe that using this type of asphalt as an acceptable method in the areas with warm climate, in case that, during summer, the paving temperature can exceed 64 °C or in the areas with a cold climate, where the paving temperature during winter can fall below –28 °C. Another well-known method for recycling the toner dust in asphalt mixtures consists in mixing the toner dusts with calcium carbonate, with 50:50 ratio. The obtained mixture is used for producing bitumen products, partially replacing the filler.

Another study [7] shows that by adding the toner dust waste in bitumen, the quality of asphalt mixtures is improved. Steve Morris [8] describes another method through which toner waste are used in producing the asphalt mixtures. The toner dust is homogenized for balancing the differences between various batches of dust waste and then aggregated. During the aggregation process, in the mixture other materials can be added, such as oily residues (engine oil). The obtained product is called TonerPave™ and exte used in the productions process of the asphalt mixtures.

On the international level, studies are developed regarding the improvement of the quality of mixtures by stirring them with synthetic polymers. Plastic plays an important role in any aspect of our life. Plastic materials are used for creating products that we are using every day, i.e. food and drinks boxes/bottles, toys, furniture, home appliances etc.

As per the researches of Mr. P.B.Rajmane et al. [4], grinded plastic waste can be used as a binder or can be stirred with bitumen for enhancing its binding characteristics. This can be a good binder for the bitumen used in the road constructions, increasing the quality of paving. Using the innovating technology, not only the high quality paving can be obtained, with a longer lifetime, but also the environment protection and obtaining new working places by creating new working points in the production factories of asphalt mixtures.

The production of the asphalt mixtures with plastic waste can be carried out using two technologies, i.e. dry procedure and humid procedure [5].

During the dry procedure, hot aggregate (170 °C) is mixed with grinded plastic waste, and then with hot bitumen (160°C). Such mixture is used for applying the asphalt on the roads. The aggregate is chosen based on the resilience, porosity and humidity absorption. The aggregate, when covered with plastic material, has improved characteristics regarding the porosity, humidity absorption and mechanical resilience (impact, pressure, abrasion etc.).

During the wet procedure and for obtaining basic bitumen modified with polymers, plastic waste is added directly in the heated bitumen (160 °C), so to form a mixture with correct dispersion of the plastic waste in bitumen. The mixture is then cooled down to 120 °C and stirred with the aggregate.

As per the studies carried out till now, plastic waste used in the production process of the asphalt mixtures can be polyethylene, propylene, polystyrene, polyester, polyethylene terephthalate. [9, 11, 12] The polyvinyl chloride cannot be used because through heating, it emits toxic gases (dioxin).

In the study carried out by Taher Baghaee Moghaddam et al. [9], that uses the wastes from the recipients made of polyethylene terephthalate, grinded to size of 2.36 mm, in various mass percentages, 0%, 0.2%, 0.4%, 0.6%, 0.8% and 1% of the aggregate particles weight, it was showed that by adding the plastic waste in the mixture, products are obtained with a resilience to fatigue higher than that of the standard mixtures. When the plastic waste is added in 20% of the total weight of the asphalt mixture, the deformation resilience of the road is the highest possible [10].

The study of Shirish N. Nemade successfully used the wastes of high and low density polyethylene, propylene and rubber waste, combining the two production procedures, dry and wet procedures. Thus, the road built with such mixture had a longer lifetime than the roads paved with standard asphalt mixtures.

For producing the asphalt mixtures, there are two types of technologies, i.e. installations with drum and installations with discontinuous processes. In both cases, the mineral aggregates are dried and heated on a rotating drum. In the discontinuous installations, the aggregates are stored in heated bunkers before being mixed with bitumen in small batches, before being stored or loaded in trucks. In the installations with rotating drum, mixing the aggregate and bitumen takes place in the same drum,
and then the mixture is stored in a bunker before being loaded in trucks to be shipped for delivery. The type of installations mostly used in the USA and New Zealand is the type with a drum, and in Europe, South Africa and Australia, the one with discontinuous installations.

3. PROPOSED MODEL FOR RECYCLING PLASTIC WASTE AND TONER DUST IN THE PRODUCTION OF ASPHALT MIXTURES

The technical issue this study resolves is proposing a modular installation that implements an efficient method for recycling the plastic waste and toner dust. This is an automatic installation and it is provided with a control unit ensuring the direction and control of the materials flow for each working point, based on the type of plastic, dust, bitumen and aggregate.

The proposed technology, as per this study, follows various specified processing steps (sorting, grinding the wastes plastic, mixing the heated aggregate with plastic waste of polyethylene, mixing the toner dust with hot bitumen, stirring the two so obtained mixtures) aiming to obtain a quality of the asphalt mixture higher than the one of standard mixture, by introducing plastic waste and toner dust, as raw materials, that not only increases the quality of the finished product but also protects the environment partially replacing the raw materials originated from natural resources and reducing the consumption of the natural resources by diminishing the surfaces covered by the wastes.

The recycling method for the plastic waste and toner dust in the process of obtaining the asphalt mixtures, as per this study, consists of covering the following preliminary steps of the production process:

a) Collecting the plastic waste;

b) Sorting the wastes;

c) Cleaning/washing the plastic waste;

d) Collecting the toner waste;

e) Treating the toner waste;

f) Packing the toner dust.

The recycling method of the plastic waste and toner dust in the production of asphalt mixtures (Figs. 1 and 3) consists of covering the following preliminary steps:

a) supplying the cold aggregate in the drying and mixing phases;

b) supplying the grinding module with washed plastic waste;

c) heating the aggregate to the temperature of 160–170 °C in the drying and mixing phases of the aggregate;

d) adding grinded plastic waste in the mixing phase over the hot aggregate. The plastic waste evenly covers the aggregate in 30 to 45 seconds. The melted plastic ensures an oily aspect of the aggregate;

e) heating the bitumen to maximum 160 °C, so to obtain a good binding;

f) mixing the hot bitumen with toner dust, at a temperature higher than the melting point of the dust, i.e. 100–150 °C;

g) grinding the plastic, reducing its dimensions to 2–4 mm and sorting it. Sorting the plastic to the required dimension takes place, for example, using a vibrating sieve/strainer. Plastic with dimensions larger than 4 mm is reintroduced in the grinding process;

h) the aggregate covered by the plastic waste is previously mixed with hot bitumen and with toner dust;

i) Evacuation/supplying the resulted mixture (asphalt mixture) in bunkers;

j) Storing or directly into the special transportation means.

As per Fig. 2 and this study, the elements of the installation are:

- storing and supplying bunkers with aggregate 1, each of them provided with separated weighing cells and positioned under each unloading conveyor; the bunkers are provided with level indicators of the aggregate;
- continuous conveyor belts provided with a weighing system 1’, with weighing cells mounted on the structure, under the belt, for weighing the aggregates flow rates transported to the drying and mixing room;
- device for drying and mixing 2;
- temperature sensors (not visible in the figure);
- grinding module (mill with blades) 3;
- device with vibrating strainers 4;
- storing device for the plastic parts with dimensions less than 2 mm 5;
- conveyor belts with closed tubing 2’;
- storing device for the plastic parts with dimensions between 2 and 4 mm 6;
- bunkers for storing hot bitumen 7;
- bunkers for storing the toner dust 8;
- mixing module 9;
- waiting bunkers (bunkers with asphalt mixture);
- burner 3’;
- exhaustors and bags filters for retaining the driven dust 4’;
- weighing device (not visible in the figure);
- supplying system (pipes) 5’;
- control and management unit 6’ based on programmable automatic devices, allowing the individual control of each device, control, direction and varying the materials flow speed and direction for increasing the installation efficiency, as well as the control of the decanter system and exhausters of the installation.

The installation, as per this study, functions as follows: the cold aggregates are coming from supplying bunkers 1, with the conveyor belt 1’ into the drying and mixing room 2, provided with temperature sensors 7’ where the aggregates are dried and heated at 160–170 °C. The drying and mixing device 2 consists of a rotating cylinder, supplies orifices, heated with a burner with central flame in counter-flow with the aggregates, provided with temperature sensor.

The drying and mixing device 2 has an auxiliary device, a burner 3’ on Diesel oil, exhausters and bags filters 4’, for retaining the driven dust. As it is about a continuous flow at the entrance into the drying and mixing room, the aggregates are weighed with a weighing device 5’ so the added quantity to be conform with the added binder weight, as per the defined recipe. Plastic waste are grinded in the mill with blades type of grinding device 3, the grinded waste being transported with a belt system with closed tubing 2’, located at the vibrating strainers 4.
The plastic particles with dimensions larger than 4 mm are reintroduced in the grinding device 3, and the plastic particles with dimensions less than 2 mm are transported with a conveyor belts system with closed piping 2' into the collecting device 5, and the conform plastic particles with dimensions between 2 and 4 mm are stored in the storing device 6.

The hot bitumen is stored in heated bunkers 7 provided with temperature sensor 7' and a heating system with oil for maintaining the bitumen at the temperature of 160–170 °C. The toner dust is stored in a closed bunker 8 provided with conveyor belts and closed piping 2' and with a controlled weighing 5' and unloading system. Bitumen is supplied into the mixing module 9 provided with controlled dosing and unloading systems.
with a temperature sensor 7° and is mixed with toner dust at a temperature between 100 and 150 °C, for about 20−30 min. Over the supplied aggregates and heated to about 170 °C, in the drying and mixing devices 2, the plastic waste particles are added (2−4 mm) and stirred for 30−40 sec.. The mixture of bitumen and toner (binder) obtained in the device 9 is transported and supplied into the drying and mixing room 2 over the aggregate and plastic mixture (the plastic covers the aggregates ensuring a shiny/oily aspect of the mixture) and so the mixing process must be continued. The obtained asphalt mixture in device 2 is evacuated into the waiting bunkers 10 or directly into special transportation means and will be used further for paving the roads.

The above mentioned installation is automatic; its functioning is carried out based on the predetermined recipes and information supplied from the process by the sensors system (not in the figure), located on/under each device. The installation, as per this study, is provided with presence sensors (not in the figure) for the dangerous areas, with audio warning and control for stopping the power supply in the installation, for avoiding the accidents.

4. CONCLUSIONS

Recycling is a method preventing accumulation the excessive waste quantity through their second processing and utilization in the production process of new materials. The installation, as per this study proposes changing of some current installations for producing asphalt mixtures and adapting it to the proposed technology for recycling the plastic waste and toner dust during the production processes of the asphalt mixtures.

Waste toner from copiers and printers is a serious solid waste, difficult to dispose. It is usually dumped in to landfills. The plastic waste and toner dust are disposed by using different methods such as incineration, landfilling which affects the environment; but by adding polymer into roads is the eco-friendly process. Disposal of plastic waste has become a problem. By developing the presented technology we contribute to the reduction of landfills surfaces and of the quantities of waste that are incinerated and also increase the road life.

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REFERENCES