MATERIAL FLOW MANAGEMENT FOR PROCESSING PLASTIC WASTE AND TONER DUST

Cicerone Laurenţiu POPA [1], Costel Emil COTEŢ [1], Simona Gheorghiţa ŞAŞCÎM (DUMITRESCU)[1] and Cristian Eugen STOICA[1]

ABSTRACT: The paper presents a method for recycling plastic waste and toner powder in the production of asphalt mixtures. In this way, we suggest the adaptation of an existing installation for the production of asphalt mixtures-to dedicated technology-that of recycling plastic waste and of toner dust. To determine which configuration ensures productivity of the installation, a preliminary architecture was modelled for the simulation of material flows. In the process of installation modelling and in order to set up structural elements in the software application Witness 14-it has been taken into consideration the fact that the material flows from the system are hybrid material flows. Taking into account this aspect, a number of simplifying assumptions have been applied in order to establish a correspondence between hybrid material flows and material flows with discrete values. Considering the fact that the presented installation is a mobile installation with a production capacity of 10 tons/hour.
KEY WORDS: simulation, recycling technological flow, plastic waste, asphalt mixture, waste toner dust.

1 INTRODUCTION

Fulfilling national targets of recovery and recycling is strictly conditioned by the implementation of selective waste collection and development of technologies for the recycling of collected waste. The biggest threat to our planet is represented by the large amount of waste. Although it can be reused as raw material in various production processes, reducing the consumption of natural resources, it gets to be disposed in waste landfills or in an uncontrolled way in nature.

Environmental issues have gained priority both nationally and internationally, with the manifestation of the effects of the planet global heating , sharp and continuous deterioration of the quality of surface water and ground water, disrupting ecosystems and affecting biodiversity, also the alarming increase of waste quantities.

In this paper we suggest the development of new technologies, which are technologically and economically feasible in order to recycle plastic waste and waste toner dust by complete harnessing of all these waste products and by getting some products which can be used in road paving.

[1]Faculty of Engineering and Management of Technological Systems, University Politehnica of Bucharest;
E-mail:laur.popa79@gmail.com; costelemilcotet@gmail.com; simonadumitrescu12@gmail.com; cristian.stoica@radacini.ro

Within the known technical solutions which have been developed so far, the recycling of plastic and toner dust in the same technological process was not approached. Depending on the area of use, asphalt contains 5-10% bitumen, the difference consisting of crumbled rocks (90-95%).

According to legislation, the issue of waste coming from electrical and electronic equipment (WEEE) is approached by HG 1037/2010 nationwide, and at the European level through the EU directive nr. 2002/96/EC. Waste toner dust is hard to use, being mostly removed to waste landfills. The method of recycling toner cartridges, most widely used, is to remove residual toner scraps, removing / shredding the cartridges and then sorting the obtained materials by category. There are various studies that analyse the quality of the asphalt which has been obtained through the introduction of plastic waste in the production process and other studies to analyse the possibility of using waste toners in manufacturing asphalt mixtures. In both cases the results were positive. Asphalt is a mixture of bitumen and mineral aggregates, used in the construction of roads.

Plastic is mainly used in packaging production industry, because it is cheaper, but, unfortunately, it is not reusable. Plastics are also used in machinery manufacturing industry , in electrical and electronic equipment manufacturing industry and not only that. Plastic waste issue is not specifically approached in European legislation, the only direct approach that establishes a goal of recycling for plastic packaging is that of Directive 94/62/EC on packaging. Recycling plastic waste is a much better option compared to the energy recovery or the disposal through waste landfill. According to the Green Card on the European strategy in the field of plastic waste that can be found in the environment, approximately 50% of all plastic materials in the EU go to waste landfills, most of them being packages. (Green Card, 2013) In this context, the study has intended to develop a method and to establish an optimal architecture of a waste recycling installation for plastic and toner dust in the production process of asphalt mixtures. The suggested technology, according to the present study, aims at taking more specific process steps (shredding plastic waste, mixing hot aggregate with plastic waste, mixing toner dust with hot bitumen, mixing the two obtained mixtures) with the final objective of obtaining an asphaltic mixture of a superior quality to the classical one , through the introduction of plastic waste and toner dust as raw material which, besides increasing the quality of the finished product, it helps environmental protection, partially replacing raw materials originated from natural resources and reducing the consumption of natural resources and also reducing the surfaces occupied by disposed waste. Bitumen is a viscous product, volatile hard, dark, obtained as a result of processing the crude oil. Polymer modified bitumen are binders to which a plastic material has been added. It significantly improves the properties of bitumen. The modified bitumen have been specially designed for being used in the construction of roads with heavy traffic. Their importance is growing.

2 MATERIAL AND METHOD

Recycling plastic bottles and moreover, recycling waste toner dust is a real challenge, given the existing technologies. The development of the method and of the installation presented in this study has started from the analysis of the existing solutions for recycling waste and from existing installations for the production of asphalt mixtures.

The working stages of the study are the following: the study of similar solutions to recycle plastic waste and toner dust in the manufacturing industry of asphalt mixture; settlement of the components of the installation for the recycling of plastic bottles and toner dust in asphalt mixtures production; settlement of installation architecture: analysis of the main elements that go into the installation structure, their processing/transport capacity, their number and their arrangement in the technological flow; simulation of material flows in order to be validated.

Texas Department of Transportation and Austin University of Texas have investigated the possibility and the potential benefits of using residual toner dust in asphalt mixtures production. The results of the study have shown that waste toner can be used successfully in the asphalt mixtures, improving the binder properties.(T. W. Kennedy, et. Al. 1997) The possibility to use plastic waste in the production process of asphalt mixtures has been studied within the LIFE + project "Polymeric waste into asphalt mixes: a way to increase sustainability of road infrastructures" (used plastic waste was of polypropylene, polystyrene, polyethylene type and also of rubber waste recycling of disused vehicles), within the project, the obtained asphaltic mixture is used for the construction of a road in Madrid. The efficiency of the mixture has been monitored for 18 months, the results of the study were positive, therefore, the road has a better resistance than the reference road, the comparison of the environmental impact of different developed asphalt mixtures shows better environmental performances, the structure of the road does not suffer. (POLYMIX LIFE+ Project, 2014) In United States Patent No. in 6,113, Tripathi et al. shows that the toner dust can be used successfully in the asphalt mixtures, taking into account its composition (styrene acrylic copolymer and carbon black), providing a good balance of properties, i.e. between stiffness and viscosity on one hand and resistance, stability and temperature sensitivity on the other hand. (Tripathi et al, 2000) Another method of plastic recycling in the production process of asphalt mixtures is presented in the study of Shirish n. Nemade, that shows that waste polyethylene of high and low density, polypropylene strap and rubber strap, can be used successfully. The roads that have been built with this asphalt have a longer life span than the roads paved with common asphalt mixtures. (S. N. Nemade, 2013) The analysis of the international databases demonstrate that plastic waste recycling and toner waste in asphalt mixture manufacturing industry can be achieved successfully, the qualities of the obtained asphaltic mixtures being superior to the classic ones; moreover, the use of such waste in the manufacturing industry brings out huge benefits to the environment. (Dumitrescu S. Cotet C. et. al. 2014) In the manufacturing industry of asphalt mixtures with plastic waste, there are two technologies: the dry process and the wet process.

The dry process consists of mixing the hot aggregate (170° C) with crumbled plastic waste, and then with hot binder (160 °C), the final product being used for the asphalting of the roads. The wet process consists of adding plastic waste directly into the heated bitumen (160°C). The obtained mixture is subsequently cooled up to 120 °C and mixed with the aggregate.

In order to establish recycling installation configuration, the virtual model was shaped in Witness 14. It includes all the structural elements and components and the simulation of the material flows from the system has been achieved. In order to simulate the material flows, simplifying assumptions have been applied, so that a correspondence should be achieved between hybrid material flows (specific to the installation) and discrete-valued material flows (which can be simulated in Witness 14). Hybrid material flows specific to the recycling installation belong to this category because crumbled/aggregate/toner dust waste cannot be completely assimilated to some fluids which circulate in pipes in order to consider continuous material flow, nor to a sequence of distinct and countable entities as in the case of material flows with discrete values. The suggested system architecture is vague, as there have been defined more than two working points. The associated model for such architecture will take into consideration the interdependence between the working points and the impact assessing of interruptions due to maintenance/repairs. The achieved model allows taking into account the average time for good functioning and the average times for reparation/maintenance for each structural element of the installation.

Through modification of existing installations for the production of asphalt mixtures and adjustment to the technology that has been proposed for the recycling of plastic and toner dust, in the production process of asphalt mixtures, we have developed a mobile installation, which has the following components:

- storage and aggregate filling bunkers 1, each of them provided with individual weighing cells located under each unloader; bunkers are provided with aggregate level indicators;
- continuous conveyors equipped with weighing system 1 with weighing cells mounted on the structure, under the conveyor, to weigh the flows of aggregate transported to the drying and mixing chamber;
- device for drying and mixing 2;
- temperature sensors (not represented);
- the way of grinding (mill with knives) 3;
- device with vibrating strainers 4;
- storage device for plastic fractions with sizes which are smaller than 2 mm 5;
- conveyor belts with closed pipe 2 ';
- storage devices for plastic fractions with sizes ranging between 2 and 4 mm 6;
- bunkers for hot bitumen storage 7;
- bunkers for storing toner dust 8;
- mixing module 9;
- waiting bunkers (bunkers with asphaltic mixture) 10;
- burner 3 ';
- dust extractions and filter bags for the resulted dust retention 4 ';
- weighing device (not represented);
- power system (pipes) 5 ';
- command and control unit 6 ' based on programmable logic controllers, allowing individual control of each device to command, direct and vary the speed and direction of the material flow for increasing the efficiency of the installation, as well as the order of the decanters and extractions system of the installation.

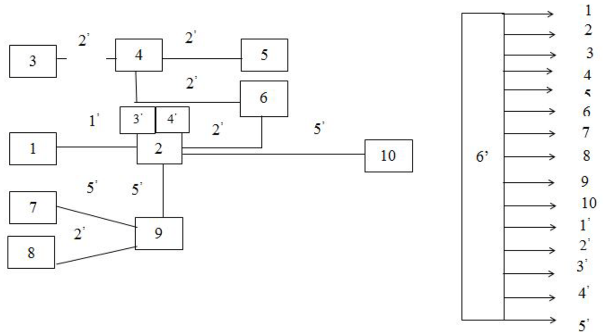

Figure 1. Flow chart of the component devices

Installation, according to this study, works like this: cold aggregates are powered from the power bunkers 1, with the help of the conveyor belt 1 in drying and mixing chamber 2, equipped with temperature sensors 7' where aggregates are dried and heated to 160-170^{0}C. The drying and mixing device 2 is composed of a rotating cylinder, power vents, heated with a flame burner in counter flow extraction with aggregates, equipped with temperature sensor. The device for drying and mixing 2 has a burner 3 as auxiliary devices' on the basis of diesel, air cleaner filter bags and extractions4', for the retention of involved dust. As it is a continuous flow at the entrance of the drying and mixing chamber, aggregates are weighed using a weighing device 5' so that the added amount should be according to the mass of the added binder, also according to the desired result set. Plastic wastes are grinded by knob device type in the mill with 3 knives, chopped waste being transported, with a system of piping bands with closed tubing 2', to the vibratory device of strainers type 4. Plastic particles with bigger sizes than 4 mm are returning to the grinding device 3, and plastic particles smaller than 2 mm are carried by a conveyor belt system with closed tubing 2' in the collecting device 5, and plastic particles in accordance, with dimensions ranging between 2 and 4 mm, are stored in storage device 6. Hot bitumen is stored in heated bunkers 7 equipped with temperature sensor 7 and oil heating system to keep the bitumen at 160-170°C. Toner dust is stored in a closed container 8 equipped with conveyor belt with closed pipe 2' and weighing system 5' and controlled unloading system. Bitumen is filled into the mixing bowl 9, module equipped with temperature sensor 7 ' and it is mixed with the toner dust at a temperature ranging between 100-150°C for about 20-30 min. Over powered and heated aggregates up to about 170 ^{0}C in drying and mixing device 2, waste particles are added to plastic (2 - 4 mm) and mixed for 30-40 seconds. Mixture of bitumen and toner (binder) obtained in the device 9 is transported and fueled in drying and mixing chamber 2 over aggregate and plastic mixture (plastic covers aggregates providing a polished/oily appearance to the mixture) and the process of mixing is continued. The asphaltic mixture obtained in device 2 is discharged in waiting bunkers 10 or directly into the special transport means, being used afterwards for road paving.

3 SIMULATION MODEL OF THE PROCESSING PLASTIC WASTE AND TONER DUST. RESULTS AND DISCUSSION

For the study of case it has been taken into account a capacity of the mobile installation of 10 t/hour, a working programme of 8 h/day, 6 days/week (including Saturday), maintenance: once/week for conveyor belts for 60 minutes, made by 2 mechanics; once a week for the mixer in which bitumen is mixed with toner dust, made by an electrician and a mechanic for 60 minutes; once a week for the oven that heats the aggregate for 60 minutes, made by a mechanic and an electrician; for the ultimate mixer in which plastic coated aggregate is mixed with the binder consisting of bitumen and toner, weekly maintenance for 60 minutes, achieved by a team made up of an engineer, a mechanic and an electrician. As mentioned above, given that we have a hybrid system, we have applied a number of simplifying assumptions so that: an aggregate unit, represented by the red colour, is the equivalent of 100 kg; a plastic unit, represented by the blue colour, represents 1 kg; a bitumen unit, represented by the green colour, represents 750 g, a toner unit, represented by the black colour, represents 250g; a bitumen- toner binder unit, represented by the light-blue colour, represents 10 kg.

The correspondence between the actual system elements and elements of the virtual model (figure 2) is seen in the table below (table 1).

Table 1 - The correspondence between the elements of real system and those of virtual system

Structural element of the virtual model	**Structural element of the installation**
Aggregate01	The aggregate silo
Plastic waste01	Silo plastic waste
Shreder01	Device for crumbling plastic waste windmill with knives type, provided with a screening device
Bitumen01	Warmed up bunker
Tonerdust01	Silo with toner dust
Owen001	Device for the aggregate heating
Plastic dust	Device for collecting plastic particles -smaller than 2 mm
Mixer01	Mixing device for plastic-coated aggregate with bitumen-toner binder
C1-C10	Conveyor belts
V2	Production capacity/ simulated period
Vehicle01	Capture device for asphaltic mixture resulting from the recycling process

In Figure No. 2 it is the virtual model of the recycling installation for plastic waste recycling and toner dust in the production process of asphalt mixtures in which parameterization was set up and process of asphalt mixtures in which parameterization was set up and the targets for the circulating entities were settled for the simulation.

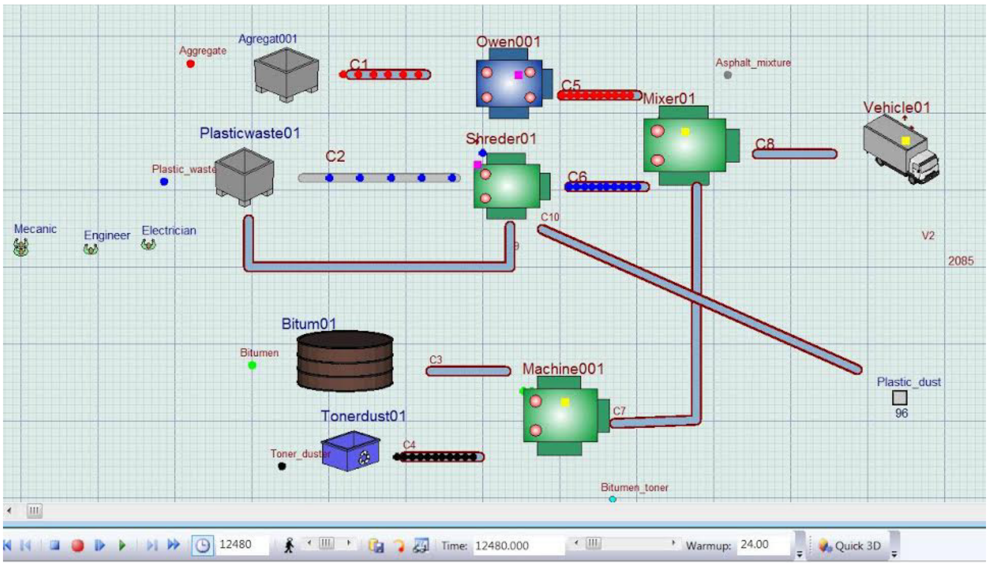

Figure 2 Virtual model of installation for plastic waste recycling and for toner dust in the production process of asphalt mixtures in Witness 14

We used an accelerated simulation in which we can achieve it in a shorter time than the real time of moving for the obtained material flows on its performance results. The material flow simulation has been performed for a period of one month (12,480 minutes), in accordance to the above mentioned processing. The quantity of the obtained finished product (asphaltic mixture) is 2085 tons. According to the achieved simulation, given that it would not conduct weekly maintenance, production capacity of the installation would be of 2132 tons/month (12,480 minutes).

In Figure No. 3 the relevant Input window type Mixer01 is presented to the structural element in which the rule for mixing plastic coated aggregate with the binder consisting of bitumen and toner has been introduced.

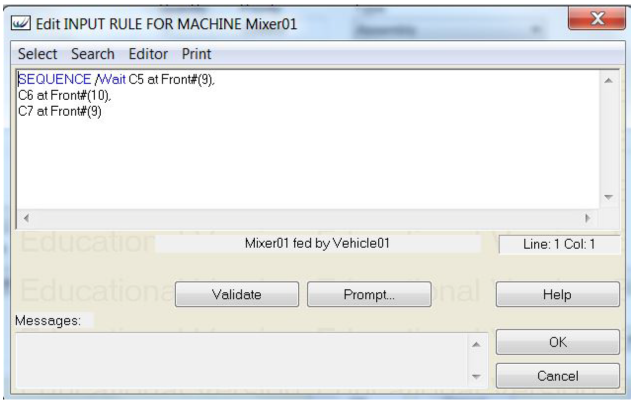

Figure 3. Mixing rule for quantities at a structural element "Mixer01"

In Figure No. 4 it is the detail window of the structural element Mixer 1 in which the average function time (2880 minutes a week) and the required time for maintenance operations (60 minutes) were defined. The human resources that are going to make the maintenance operations were also provided.

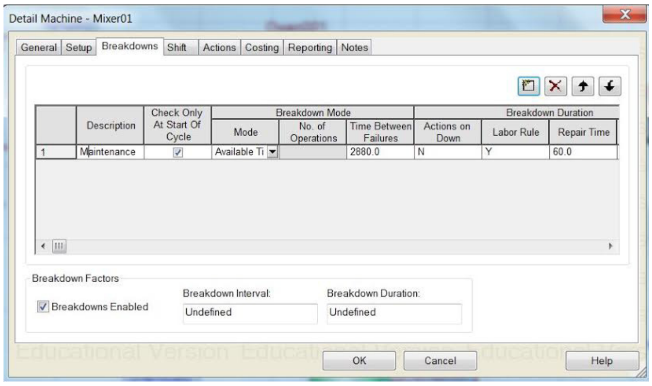

Figure 4. Maintenance stroke for a structural element "Mixer01"

In Figure No. 5 it is presented the report on the operation of the C1 conveyor which is going to transport circulating entities of "Aggregate" type to the oven (Owen001). The report was generated after a simulation for a month of operation (12,480 minutes) and it shows that it works properly in 88% of the total time, it presents blockages to 5% of the total time.

The structural element is stopped for maintenance operations or it is pending for human resources carrying out maintenance for 7% of the total time.

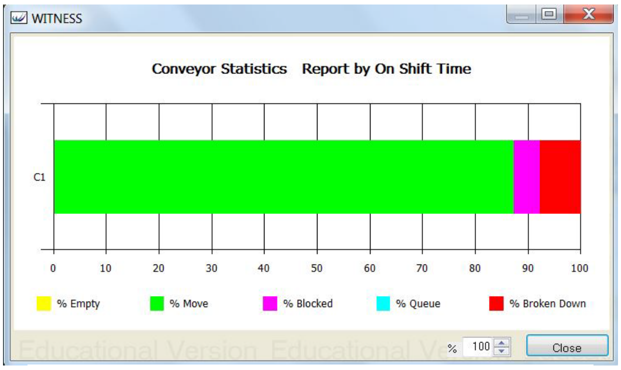

Figure 5. Report on the conveyor functioning that carries the aggregate into the oven

4 CONCLUDING REMARKS

Plastic waste and waste toner dust recycling is a problem for Romania and not only that. As it can be seen from the above simulations, the developed technology can be successfully used in the production activity of the tar mixture. Studying the current status of research in this field, it has been shown that there is not a developed technology to recycle plastic waste and toner dust in the production process of asphalt mixtures, despite the huge benefits which are offered by the existence of such technologies, both for the environment and for the asphaltic mixtures producing industry. The presented paper develops an innovative solution, in terms of the magnitude and complexity of the suggested issues, owing to the thing that two types of waste is achieved, partially replacing the natural resources which are used in production activity, materials having utility in road construction activity.

The developed model, for which this case of study has been done, is an useful tool to evaluate the various working scenarios, in order to determine which configuration ensures optimal productivity of recycling and production installation.

The objective is for the future construction of a pilot installation and the testing of the obtained material, as there has been no operation in such an installation and no solution for toner dust recycling in Romania.

5 ACKNOWLEDGEMENTS

The work of Simona Gheorghiţa Şaşcîm (Dumitrescu) was supported by project SOP HRD – PERFORM/159/1.5/S/138963.

6 REFERENCES

►*Green Card on European strategy in the field of plastic waste in the environment* (2013). European Commission, Brussels, available at: http://cor.europa.eu/en/activities/stakeholders/Documents/comm_123_2013_en.pdf

►Thomas W. Kennedy, Robert B. Mc. (1997) *Use of Waste Toner in Asphaltic Concrete*, Research Report 3933-lF, conducted for the Texas Department of Transportation by the Center for Transportation Research Bureau of Engineering Research the University of Texas at Austin.

►*Polymer Wastes in Asphalt Mixes: a way to increase sustainability of road*, POLYMIX LIFE+ Project Newsletter- Nº4 – (2014), available at: http://www.giteco.unican.es/polymix/Documentation/NewsletterN4eng.pdf.

►Tripathi et al, United States Patent no. 6,113,681, (2000)

►Shirish N. Nemade, Prashant V. Thorat. (2013). *Utilization of Polymer Waste for Modification of Bitumen in Road Construction*, Sci. Revs. Chem. Commun, p. 198-213.

►Şaşcîm (Dumitrescu) S. Coteţ C. Popa L. Stoica G. 2014, *Method and Instalation for Recycling Plastic Waste and Toner Dust in the Production of Asphalt Mixtures*, Proceedings in Manufacturing Systems, Volume 9.

►Witness 14 user manual.