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OPTIMIZING ASPHALT MIXTURES MATERIAL FLOW

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This paper presents a method of recycling plastic waste and toner powder in asphalt mixtures production process and the approach that is used to establish optimal architecture for processing the appliance. The virtual model of the processing architecture was developed in Witness 14 and it will be used as a tool for identifying and eliminating flow concentrators and for obtaining improved system productivity. Simulation of the proposed production system offers the ability to view recycling and production processes reports, analysing manufacturing processes and material flow in order to improve productivity.

Keywords: material flow; modelling; simulation; plastic waste, toner dust, recycling.

1. Introduction

Waste is a problem for the environment, society and economy. Correct management of waste protects human health and implicitly helps the environment, also helping to conserve natural resources. Recycling has a beneficial effect on the environment by reducing the amount of waste disposed in landfills, thus reducing pollutant emissions. Moreover, recycling contributes to satisfy the demands of materials from economic production, alleviating the need for extraction and refining of raw materials. [1]

Plastic materials are hugely used worldwide, due to the advantages plastic presents: low cost, low weight, high manoeuvrability, and cheap manufacturing technology. But plastic is a very important issue for our country, because of the low level of recycling. Their consumption growth, especially in recent years, has brought to the alarming increase in the number of packages irresponsibly removed in nature. Collecting and recycling them reduce the negative environmental impact.

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Plastic waste can be recycled to obtain fibbers that can be used as raw material in various industries. The advantages of products made from recycled plastic consist of a manufacturing cost that is cheaper than those made from raw materials. Packaging generates the largest quantity of plastic waste but other industries such as auto industry, electrical and electronic equipment industry, etc. are also plastic waste generators. European Directives establish strict targets for recycling packaging waste by types of material.

Empty cartridges are consumable waste from the use of computer and office equipment supplies (waste from electrical and electronic equipment). They are considered waste electrical and electronic equipment (WEEE) if they are given together with some old equipment. A large quantity of used cartridges is reusable (after a technological regeneration process), thus a new product being obtained. Either they are recycled, or they are regenerated for being reused, in both processes toner powder is resulting, powder for which, so far, a method of recovery has not been developed nationally, the powder being eliminated. Toner is a powder used in laser printers and photocopiers to form the printed text and images on paper. At EU level, Directive 2012/19 / EU on electrical and electronic equipment waste (WEEE) introduce higher targets for WEEE collection since 2016. In accordance with the legal framework, the current collection rate of 4 kg / inhabitant remains until 2016, but after the first half of the year, the minimum collection rate will be 45% of the weight of electrical and electronic equipment that has been placed on the national markets. [3] The European Commission has developed and adopted Directive 94/62 / EC, intended to help the reduction of packaging waste, the directive in which there are prescribed targets for recycling and recovery of waste. By transposing this Directive in Romanian legislation, the responsibility on implementing this document lies with economic operators who are producing, bringing to market and distributing packaging and packaged products.

Collection and recycling of packaging waste is mandatory in Romania and in other European countries. Regulating the production and management of waste in our country is made by Law no. 211/2011 on waste regime. [2]

Under these circumstances, considering that nationwide there has not been developed a technology for recycling toner powder and giving the large amount of generated plastic waste and given the negative effects to the environment by eliminating plastic waste and waste cartridges / toner powder in landfills, the development of some technology for recycling these types of waste is a necessity. The technology for recycling plastic waste and toner powder in asphalt mixtures production process was developed starting from classic technologies used to produce asphalt mixtures.

The main purpose of this article is to present the development and validation of a simulation model that allows to evaluate and analyse scenarios for recycling technology of plastic waste and of toner powder in the production process of asphalt mixtures. Therefore, the research issue was to investigate, define and validate the variables that compose the simulation model and also its design and validation. For the development of the computer model, techniques from the system dynamics field have been used.

Production is the organized social activity in which the labour force, using the means of production, in organized social activities and formations, uses and modifies the natural elements in order to obtain material goods with market selling value.[11] Generally, line productivity decreases with the increase of standard deviation, a fact which is supported by the speciality literature; according to that, it is a reasonable assumption for most manufacturing processes (because most processes cannot be interrupted) [12,13,14].

The production system represents all the natural and artificial elements (raw materials, materials, energy, tools, devices, technological equipment, buildings), labour force and production relations, concepts, work organization and management of production, aiming to obtain final products and services that can be sold on the market.[15]

Installations for waste processing have the same structural elements as manufacturing architectures specific for industrial engineering (workstations, transport systems, transfer systems and storage systems), and the manner in which the modeling, parameterization, establishment of the trajectories and performance indicators centered on productivity correspond for both types of architectures. The way- in which they achieve modelling, parameterization, establishment of the trajectories and performance indicators centered on productivity- corresponds for both types of architectures. [11]

The manufacturing system fulfills tasks of (direct) physical achievement for the product, through physical-chemical transformations and shape transformations over the material flow using energy flow; therefore, technogical information (informational flow) is transferred to the product under imposed economic conditions . The material flow includes raw material, feedstock materials (coolant, oils, putties, thinner, varnish, etc.), intermediate and finished products, tools, devices, checkers. The informational flow is made up of all original technical-economic data and technological information relating to the manufacturing process, as well as organizational and economical information. [16, 17].

A processing architecture involves one or more installations. Manufacturing architecture is a generic architecture in which the trajectories are determined by a succession of structural elements located so as to contribute to the achievement of a product. [11]

We can define four types of structural elements and two types of auxilliary elements for a manufacturing architecture: workstations, transportation systems, transfer systems, storage systems. Auxilliary elements: circulating entities and human operators. [11]

2. Literature Review

European legislation transposed in our country has imposed an approach to the issue of waste which starts from the need to save natural resources, reduce management costs, to find effective solutions for recycling and to reduce the negative impact of waste on the environment. Developing a solution for recycling toners brings major benefits to both the environment and the manufacturing industries. We propose that inside the appliance of asphalt mixtures production, plastic waste (plastic bags / plastic containing dirt, sand, gravel) to be used as raw materials besides toner powder waste. This plastic cannot be used in other recycling industries because of existing impurities. We also suggest that in the process of asphalt mixtures production, plastic waste from medical activities to be used, waste that previously has been treated through a chemical sterilization process. Waste recovery in construction materials is an important field to the extent that the used raw materials are not subject to rigorous quality standards. Plastic bags are mainly composed of low-density polyethylene (LDPE). They are commonly used for packaging and protecting products. The toner powder is a mixture of carbon powder, iron oxide and polymers. It is proven that adding certain binder polymer in asphalt mixtures, road pavement performance can be improved. Adding polymers gives greater resistance to traffic and thermal cracking. Polyethylene is widely used as plastic material and has proven to be one of the most efficient additives. [4] Within economic value, it shows that the recycled plastic could reduce the cost of building roads, because this recycled material is cheaper than bitumen, and easier to obtain. Furthermore, plastic improves the performance and life level of the road. According to Wan Mohd Nazmi Wan Abdul Rahman et. all's study, it can be concluded that the use of recycled plastic in the production process of asphalt mixtures has more advantages compared with conventional asphalt mixture, particularly within permanent deformation. Taking into account environmental and economic aspects, it is considered appropriate to use plastic waste for obtaining asphalt mixtures used for road paving. [5] Experiments conducted by several institutes have indicated that shredded plastic waste, when added over warm unit will form a thin layer of plastic over aggregate, giving better resistance to water and better performance over a period of time. Plastic waste such as bags, disposable cups, laminated bags, and other plastic packaging used for food production can be used to asphalt mixtures production. [6] Plastic waste resulting both from the sorting of domestic waste and industrial waste can be used in asphalt mixtures production. Plastic waste, mainly used for pallets, is made from polyethylene, polystyrene polypropylene. Their melting point is ranging between 110^{0}C – 140^{0}C. During warming they do not produce toxic gases; moreover, melted plastic forms a film when sprayed on hot aggregate on 160^{0}C. Plastic aggregates coated in plastic are a better raw material for the construction of flexible road pavements. [7]

A research project, 7-3933, run by the Texas Department of Transportation of the University of Texas, Austin, has investigated the feasibility and potential benefits of using toner powder in the production of asphalt mixtures. Study results showed that the toner powder can be used in asphalt mixtures, providing a good balance of properties, between stiffness and viscosity on one hand and resistance, temperature, stability and sensitivity on the other hand. [8] The industry producing asphalt mixtures for paving is that segment of industry that builds highways, streets, airport runways, parking areas, driveways, sidewalks, bike lanes and areas of sport and playgrounds. Asphalt is a mixture between aggregate and bitumen, and in our case, plastic waste and toner powder. Bitumen is a black sticky material, naturally derived from fractional distillation of crude oil, being used as a binder in road construction. [9]

3. Simulation model

Currently, numerical simulation plays one of the key roles in engineering. Simulation is used to analyse system response to certain inputs according to a script. It applies to describe, analyse and predict the behaviour of processes and to develop control and optimization strategies. Dynamic simulation is useful throughout the life of an installation: from conception to decommissioning. It is obvious that the production process is a complicated system that involves sets of tasks, materials, resources, products and information. Making an analysis of the production process there is the advantage of understanding how production is done, identify problems and differences between actual performances and expected / proposed objectives. This paper presents the virtual model of an appliance for asphalt mixtures production, partially replacing raw materials with recycling materials, namely plastic waste and powder coming from recycling toner powder. To determine the configuration that ensures optimum productivity of the processing appliance we have designed a virtual model of its functioning in Witness 14, a model that allows simulation for the circulation of material flows. Mathematical modelling, underlying the achievement of virtual model, considers that the waste-recycling appliance for glass waste is, in terms of material circulating flows, a hybrid system with a diffuse architecture. For such hybrid architecture, specific performance parameters, associated to productivity, are the average amount processed on a time period at a recommended broadband speed. The appliance for processing plastic waste and toner powder in the production of asphalt mixtures was achieved through modification of existing appliances for the production of asphalt mixtures and adaptation to the proposed technology. The developed appliance has the following components:

- Storage and supply bunkers with aggregate (there are four supply bunkers, one with 30% big aggregate >20 mm, the second one with 30% medium aggregate -10 to 20 mm, the third one with 20% aggregate <10 mm, the fourth four - $CaCO_3$ filler micronized <0.1 mm);
- Continuous conveyor belts equipped with weighing system;
- Aggregates mixing device;
- Drying and mixing device;
- Grinding module (knives mill), provided with a sieve device (vibrating sieve);
- Module for plastic fractions storage with the size smaller than 2 mm;
- Closed pipe transport conveyors to transport toner powder;
- Bunkers for storing hot bitumen;
- Bunkers for toner powder storage;
- Module for bitumen – toner mixing;
- Waiting bunkers (bunkers with asphalt mixture);
- Ventilators and bag filters for capturing generated dust; - unrepresented in the virtual model;
- Supply system for bitumen / bitumen-toner binder.

Appliance - figure number 1. The virtual model of the appliance: it works, so cold aggregates are fed from the four supply bunkers (Aggregate 1 - 30% of the total weight of the unit, from the bunker with large unit, with sizes larger than 20 mm, Aggregate 2 - 30% of the total weight of the aggregate in the bunker with the medium aggregate with sizes ranging from 10 to 20 mm, Aggregate 3 - 20% of the total weight of the aggregate, from the bunker with small aggregate, with the size smaller than 10 mm, Aggregate 4 - 20% of the total weight of the Aggregate, from the bunker with micronized filler aggregate, with sizes smaller than 0.1 mm), using conveyor belts in the Aggregate - Mixer Aggregate mixing module. From Mixer Aggregate module, the mixed aggregate in predetermined proportions is transported using the conveyor belt in the drying and mixing - Oven, equipped with temperature sensors where aggregates are dried and heated to 160 - 170^{0}C.

The drying and mixing "Oven" device is composed of a rotating cylinder, supplying vents, warmed by a central flame burner, in a contrary current to aggregates, equipped with temperature sensor. The drying and mixing "Oven" device has a burner as auxiliary devices, a burner that uses diesel as fuel, and filtration systems for capturing outcoming dust. Being a continuous flow at the entrance of the mixing module for aggregates "Mixer - Aggregate", aggregates are weighed using a weighing device; the added amount in the module has to be according to the mass of the added binder, according to the established recipe.

Plastic waste is grinded in the grinding device type knives mill, device that is provided with a sieving module, type-vibrating sieve. The grinding and sieving device is represented in figure number 1 as the "Shredder".
Waste that is shredded and sorted by size, is transported, with a closed tubing system of belts, depending on the size of plastic particles, like this: plastic particles larger than 4 mm are returning in the grinding and sieving device "Shredder", and plastic particles smaller than 2 mm are carried on a closed tubing system conveyor belts, in the collecting device "Plastic - dust" and the compliant plastic particles with sizes between 2 and 4 mm in mixing device Mixer - Asphalt. Hot bitumen is stored in a heated bunker "Bitumen" equipped with temperature sensor and oil heating system, in order to keep the bitumen at 160 -170^{0}C. Toner powder is stored in closed bunker "Toner - dust", equipped with closed tubing conveyor belt and with a system of controlled weighing and unloading. Bitumen is supplied into the mixing module "Mixer – Bitumen - toner" equipped with temperature sensor and it is mixed with toner powder at a temperature of 100-150^{0}C for about 20- 30 minutes. Over the aggregates loaded and heated up to about 170^{0}C, in the drying device "Oven" and transported to the mixing module Mixer_Asphalt, plastic waste particles (2 - 4 mm) are added and mixed for 30-40 seconds. The mixture of bitumen and toner (binder), obtained in the device "Mixer – Bitumen - Toner" is transported and supplied into the mixing module Mixer - Asphalt over the mixture of aggregates and plastic (plastic covers aggregates providing a glossy/oily appearance to the mixture) and the mixing process continues. Asphalt mixture, obtained in Mixer - Asphalt device, is discharged into the waiting device "Bf - AM" and it will be used to pave roads.

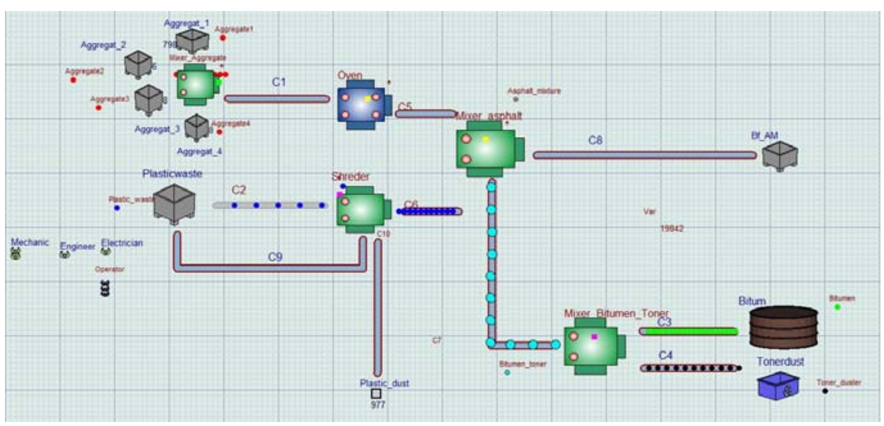

Fig. 1 The virtual model achieved in Witness 14

Correspondence between the real system elements and virtual model elements (figure 1) is the one in the chart below (chart number 1)

Table 1

Correspondence between the elements of the real system and the elements of the virtual system

No.	Structural element of the virtual model	Structural element of the appliance
1	Aggregat_1	Silo with aggregate > 20 mm
2	Aggregat_2	Silo with aggregate from 10 to 20 mm
3	Aggregat_3	Silo with aggregate < 10 mm
4	Agrgegat_4	Silo with micronized aggregate <0,1 mm
5	Plastic_waste	Silo with plastic waste
6	Shredder	Plastic waste shredding device type knives mill equipped with a vibrating sieves device
7	Bitumen	Bitumen heated bunker
8	Toner dust	Silo with toner powder
9	Mixer_Aggregate	Device that mixes aggregates of various grits
10	Oven	Device for heating the mixed aggregate
11	Plastic_dust	Device for collecting plastic particles smaller than 2 mm
12	Mixer_Asphalt	Device for mixing plastic coated aggregate with bitumen - toner binder
13	Mixer_Bitumen_Toner	Device for mixing bitumen with toner powder
14	C1-C10	Conveyor belts
15	V2	Production capacity / simulated period
16	Bf_AM	Device for taking over asphalt mixture resulting from the process

For the case study it has been considered a capacity of mobile appliance of 10 t / hour, a working program for 8 hours / day, 5 days / week, 52 weeks / year, maintenance like this: once / week for conveyor belts for 60 minutes, made by two mechanics; once / week for the mixer that mixes the bitumen with toner powder, made by an electrician and a mechanic for 60 minutes and semester maintenance is performed for the same mixer for one day by a team made up of a mechanic and an electrician; once / week for the oven heating the aggregate for 60 minutes, made by a mechanic and an electrician and also for the oven semester maintenance for one day, undertaken by a team made up of an electrician and a mechanic; for the final mixer in which plastic covered aggregate mixes with the binder consisting of bitumen and toner, weekly maintenance for 60 minutes, made by a team made up of an engineer, a mechanic and an electrician and also for the final mixer - semester maintenance, for one day, undertaken by a team made up of an engineer, a mechanic and an electrician; for the grinding and sieving device, monthly maintenance performed for 3 hours by a team made up of an electrician and a mechanic. As you can see in the capture of the virtual model for the appliance in figure number 1,the assigned human resources are: an electrician, a mechanic, an engineer and three operators.

In figure number 1, it is the virtual model of the appliance for recycling plastic waste and toner powder in the asphalt mixture production process, in which parameterization has been undertaken and the trajectories for the circulating entities have been set in order to simulate. We have used an accelerated simulation in which we can get less time than real time for the resulting material flows displacement. It refers to its performance; material flows simulation was performed for a period of one year (124800 minutes), under processing conditions mentioned above, the amount of the obtained final product is 19842 tons.

Fig. 2 shows the Input window corresponding to the structural element Mixer_Aggregate, in which the mixing rule for various grits aggregates was introduced.

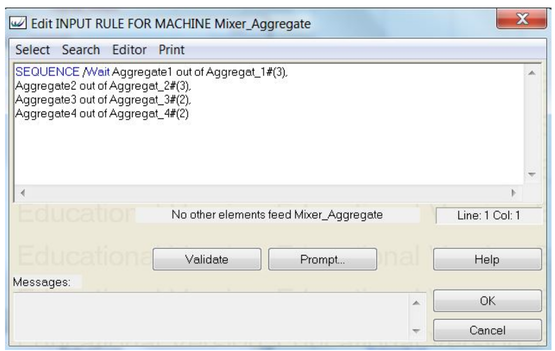

Fig.2 - Mixing rule for the amounts to a structural element Mixer_Aggregate

In fig. 3.a and 3.b the detail window is presented for structural elements Oven and Mixer - Asphalt in which the average times for good operation were defined. There were also human resources that were assigned to do the maintenance operations. For the Oven structural element, as it can be seen in the achieved capture, average time for good operating environment (2400 minutes - a week and 62400 - a semester) and the time required for maintenance operations (60 minutes for weekly maintenance and 240 minutes for semester maintenance). For Mixer - Asphalt structural element, as it can be seen in the achieved capture, average time for good operating environment (2400 minutes - a week and 62400 - a semester) and the time required for maintenance operations (60 minutes for weekly maintenance and 480 minutes for semester maintenance).

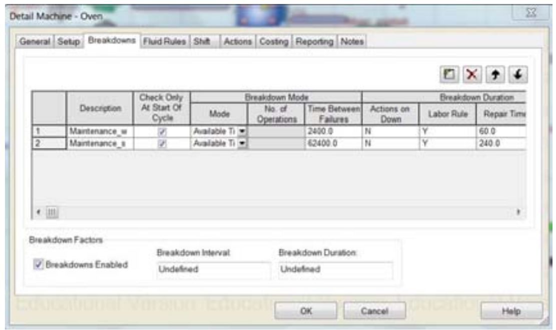

Fig. 3.a Maintenance times structural element "Oven"

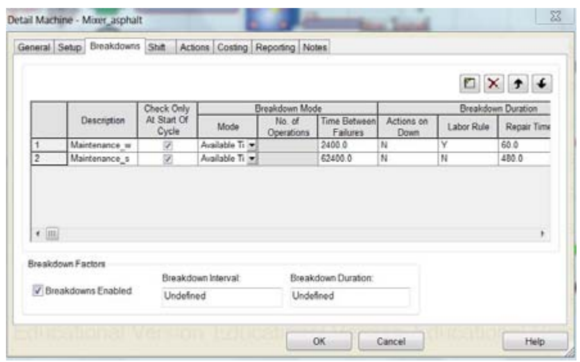

Fig. 3.b Maintenance times “Mixer_Asphalt”

Fig. 4 presents the report on the functioning of the conveyor – C 1, conveyor that will transport circulating entities type "Aggregate" to the oven (Oven). The report was generated by a simulation related to an operational year (124800 minutes) and it shows, as you can see from the shown screen, the fact thatit works under normal operating parameters 85% of the total time, it has blockages for 12% of the total time. The structural element is closed for maintenance operations or it is awaiting a human resources performing maintenance 2% of the total time.

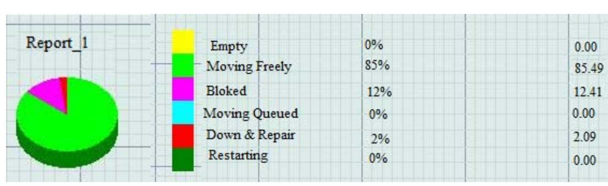

Fig. 4 Report on the functioning of the C 1 conveyor

4. Conclusions

In the above case study we proposed the establishment of an optimal architecture for an innovative appliance for plastic waste and toner powder recycling in asphalt mixtures production process, starting from classic appliances for the production of asphalt mixtures. Simulation of the system for recycling plastic waste and toner powder in asphalt mixtures production process was successfully used to develop an optimized material flow. The model was designed to assist decision-making process of those responsible for waste management, to support better planning on the use of generated waste and ultimately, to allow assessment, in advance, of the possibility of using this waste as raw materials in manufacturing industry of asphalt mixtures, to minimize the environmental impact caused by waste disposal in landfills and to reduce consumption of natural resources.

The presented technology development contributes to reducing the areas occupied by landfills producing a premium quality of asphalt mixtures that are superior to the classical ones. Presented research challenges are determined mainly by the lack of such a practice in the industry producing asphalt mixtures and the lack of a sufficient number of similar national research results. The results of the simulation study are useful to demonstrate the applicability of this technology and to identify priority areas for future research.

The developed virtual model can be successfully applied in the production of asphalt mixtures either by modifying an existing facility or by developing a new facility.

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