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Efficient technical solution for recycling textile materials by manufacturing nonwoven geotextiles

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Abstract.   This paper aims to support the concept "circular economy" that was developed recently. It presents an efficient method for creating a closed loop in the Romanian textile industry by recycling textile materials, such as polyacrylonitrile knitted old products (collected from population) and small polyester woven patches from pre-consumer waste (garments manufacturing companies). Because of their properties, nonwoven geotextiles have many advantages in railways reinforcement, slopes stabilization, erosion control, drainage, filtration, paving roads, crops coverings, etc. The nonwoven geotextiles were obtained from three fibrous blends based on recovered fibers (PES and PAN) and fibers at first usage (PP) in different ratios. All experimental variants were processed on the same manufacturing line with the same technological parameters. There were tested the main physical and mechanical parameters and it was applied single factor ANOVA method for thickness, bulk density, air permeability and static puncture strength. The conclusion is that adding PP fibers in the blends represents a very important factor for geotextiles characteristics but it possible to decrease the ratio from economical reasons and still maintain a high quality level of nonwovens.

1. Introduction

The concept of "circular economy" is based on optimizing industrial systems/processes by using the principles: zero waste, no pollution, cradle-to-cradle, closed loop production systems in which waste is seen as input, and so on. In January 2012 the first report related to circular economy model was developed by *McKinsey & Company* describing the benefits across the EU. This report presents some case studies and also estimates shifting towards circularity could add $1 trillion to the global economy by 2025 and create 100,000 new jobs within the next five years [3].

On 17 December 2012, the European Commission published a document entitled *Manifesto for a Resource Efficient Europe*. This manifesto clearly stated that "In a world with growing pressures on resources and the environment, the EU has no choice but to go for the transition to a resource-efficient and ultimately regenerative circular economy" [3] It was created a *Circular Economy 2020 Vision* by taking into account social and ecological impact of industrial processes.

A special attention is given to the *Circular Textiles Industry* because this domain follows the same old linear pattern "take-make-consume-dispose". Specialists know that the trend is to produce low cost garments in high volumes and quickly dispose them after a short time of wearing. In this way, waste is

produces in large quantities - so called *post-consumer waste*, collected from population. Nowadays this type of waste is burned or landfilled. Another source of waste is coming from textile manufacturing industry - so called *pre-consumer or technological waste*.

The *Circular Textiles Industry* offers an opportunity to reinvent and rethink the business model, making it more sustainable and competitive. Must be taken measures to re-use and stimulate industrial symbiosis, this means to turn one by-product or waste into a new raw material for another sector of the textile industry or for another industry.

A valuable idea is to **recycle textile materials**. In case of post-consumer waste, population must understand how to separate different types of materials before their disposal, selecting non-clothing articles from clothing. For technological waste, all manufacturers must be trained to collect it separately, depending on the raw material type (fibers): cotton, wool, bast fibers, polyester, polyacrilonitrile, polypropylene, polyamide and so on [2].

The fabrication of nonwovens is an efficient industrial solution. This paper presents the results of a research study concerning the recycle of synthetic fibers for producing nonwoven geotextiles.

2. Nonwoven geotextiles

Geotextiles are textile materials (woven or nonwoven) used in or near the ground, in a variety of weights - from light filter materials for drainage systems to heavy protection materials for landfill construction, roads reinforcement, rail construction etc. They play an important role in environment engineering projects including erosion control, prevention of groundwater contamination, soil and slopes stabilization, revegetation projects and so on. Also they are used in agriculture as crop covers or ground covers. The required properties and functions of the geotextile are related to its application [2].

Figure 1 shows the classification of nonwoven geotextiles by taking in consideration the nature of raw materials (blends from 100% synthetic fibers, blends of 100% natural fibers and mixed blends - for example straw fibres and a synthetic mesh to form an erosion control geotextile).
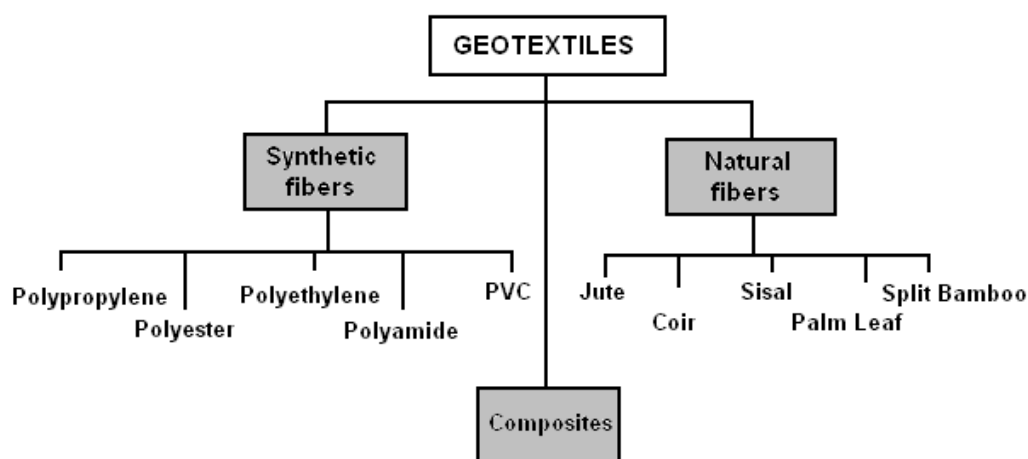
Source: www.fao.org

Figure 1. Classification of nonwoven geotextiles after the type of raw materials.

The global analysis for 2013 shows that nonwovens are the major type of geotextiles with a percent around 65% of entire market [4]. The advantages of nonwoven geotextiles are: lightweight; isotropy related to elasticity; permeability to air and water; low humidity; resistance to rotting, chemicals, bacteria and fungus; temperature fluctuation tolerant, etc.

Each year *EDANA (European Disposables and Nonwovens Association)* describes in facts and figures the evolution of nonwovens market. It is a reality that world market of nonwoven geotextiles is growing year after year, new applications are found and new products are manufactured. Geotextiles global market will reach $8,632.83 Million by 2019 [5].

In the past years, polypropylene fibers are the most used for geotextiles because they have some significant advantages: lightweight (0.91-0.93g/cm^3); low moisture absorption (moisture regain 0); good mechanical resistance (breaking elongation 40-70%); high chemical and corrosion resistance (resistant at pH = 3...13); excellent abrasion resistance; good industrial processing.

3. Method and experiments
Nonwovens are textile materials formed by filaments or fibers randomly arranged and bonded together into a planar structure. The properties of nonwoven geotextiles depend on factors as: the type of fibers, the technology which determines the structure, the bonding process and the bonding agent.

The main goal of the research was to produce *nonwoven synthetic geotextiles* by recycling textile waste such as: **polyacrylonitrile** knitted old products (collected from population) and small **polyester** woven patches from pre-consumer waste (garments manufacturing companies). This decision was taken after analyzing the quantities of different types of textile waste in the North-East region (Iasi, Bacau, Botosani, Suceava, Neamt and Vaslui counties) during one year. In fact, the PAN fibers form the major component - over 75% - in the amount of recycled fibres fed to the production line.

Figure 2 shows the technological process for obtaining nonwovens from *Nonwovens Micro-production Laboratory* of Faculty of Textiles, Leather & Industrial Management, "Gheorghe Asachi" Technical University of Iasi. After recovering synthetic fibers from waste, the next stage is web (fibrous layer) forming, followed by the mechanical bonding by needle punching.
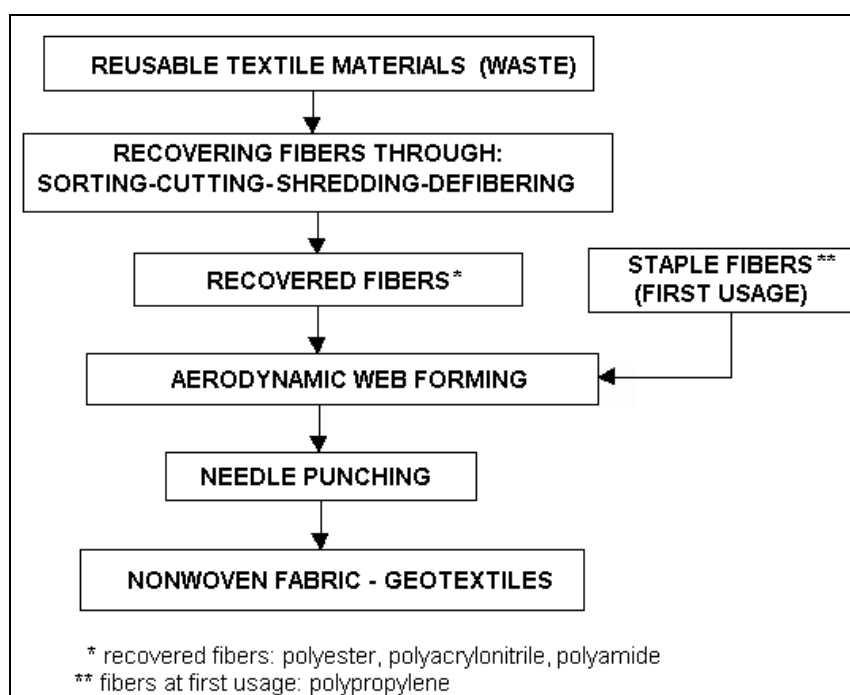

Figure 2. Technological process for obtaining nonwovens.

There were processed three different fibrous blends:
- 67% PP (polypropylene fibers at first usage) + 33% recycled fibers (blend PP67);
- 50% PP + 50% recycled fibers (blend PP50);
- 33% PP + 67% recycled fibers (blend PP33).

Technological parameters of the processing line were maintained constant for all blends because the influence of PP fibers ratio upon mechanical properties of nonwovens was determined by applying single factor ANOVA method. The interpretation will be correlated to the goal of optimizing the manufacturing costs for nonwoven geotextiles with content of recycled fibers.

These parameters are: delivery speed for carded web 11.5m/min, feeding speed for WF machine 12m/min, taking speed of TB 0.8m/min, delivery speed after NP machine 0.9m/min, number of needle punches 8 needles/cm^2., and the width of fibrous layer 1.9m.
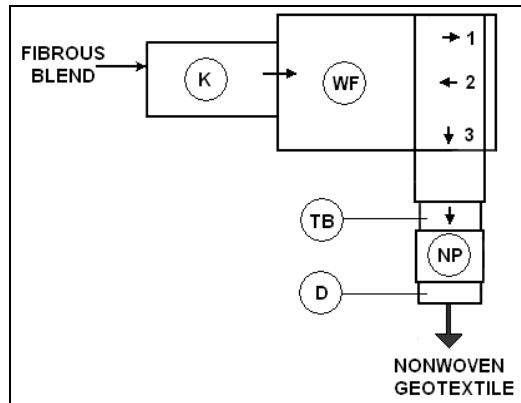

Figure 3. Production line for nonwovens.

K   - carding machine
WF - dry-laid web formation machine
TB - transportation belt for fibrous layer
NP - needle punching machine
D   - nonwoven delivery (rolling device).

4. Results and interpretation

For each variant of fibrous blend (encoded PP67, PP50 and PP33) there were tested the main mechanical properties: thickness [mm], specific weight [g/m^2], apparent or bulk density [kg/m^3], static puncture strength [kN] and air permeability [m^3/min.m^2]. The results are shown in *Table 1*.

All samples were conditioned in standard atmosphere accordingly to ISO 554:1976.

Table 1. Main mechanical properties for experimental geotextiles

		Thickness[1] (mm)	Specific weight (g/m^2)	Bulk density[2] (kg/m^3)	Static puncture[3] strength (kN)	Air permeability[4] (m^3/min.m^2)
PP67	$\overline{x}$	5.394	80.50	17.75	0.98	60.47
	CV, %	*5.67*	*5.08*	*8.12*	*27.16*	*7.78*
PP50	$\overline{x}$	5.093	121.30	23.88	0.36	69.14
	CV, %	*6.53*	*6.84*	*7.76*	*31.26*	*7.87*
PP33	$\overline{x}$	4.553	132.70	29.14	0.22	75.68
	CV, %	*6.86*	*9.15*	*5.53*	*41.0*	*8.26*

[1] single layer thickness accordingly to ISO 9863-2:1996
[2] computed as a ratio of weight on surface unit and thickness of the sample (S=0.01m^2)
[3] ISO 12236:2006
[4] pressure difference $\Delta p=30$ N/m^2.

Single factor ANOVA (ANalysis Of VAriance) or one-way ANOVA technique was applied for each fibrous blend, taking in consideration four properties (also named variables) of the geotextiles: thickness, bulk density, air permeability and puncture strength. The considered factor is the *percent of PP fibers* at first usage in the blend. This factor has three levels of variation: 67%, 50% and 33% (q=3).

At each level of the factor there were n=10 experimental data for every considered variable.

It was considered a level of significance $\alpha=0.05$.

He working hypotheses are:

H_0: all population means are equal (the factor has not a significant influence upon variable)
H_1: all population means are not equal (the factor has a significant influence upon variable)

The one-way ANOVA results are shown in *Table 2*. Abbreviations have the following meaning:
- C, D, R - preliminary statistics [1];
- $\overline{\overline{x}}$ - general mean of the three group means (number of groups = number of levels of variance for the considered factor);
- SS - sum of squares (W - within the groups, B - between the groups, T = total);
- df - degrees of freedom (W - within the groups, B - between the groups, T = total);
- MS - mean square (W - within the groups, B - between the groups, T = total);
- Fc - computed value as a ratio between MS_B and MS_W;
- Ftab - stardard value found in tables for Fisher distribution at $(1-\alpha; df_B; df_W)$ [1].
  By comparison Fc with Ftab it can be formulated the conclusion on null hypothesis. In all cases Fc > Ftab, this means H_0 is false and it is rejected with 0.95 probability.

Table 2. One-way ANOVA results.

Property / Computed value	Thickness	Bulk density	Air permeability	Static puncture strength
C	150.40	707.62	2043.44	15.57
$\overline{\overline{x}}$	5.013	23.587	68.167	0.519
D	760.354	17413.564	141196.177	12.115
R	757.637	17340.551	140380.596	11.295
SS$_B$	3.632	649.707	1191.98	3.214
SS$_W$	2.717	73.013	815.581	0.820
SS$_T$	6.349	722.72	2007.561	4.034
df$_B$	2	2	2	2
df$_W$	27	27	27	27
df$_T$	29	29	29	29
MS$_B$	1.816	324.854	595.99	1.607
MS$_W$	0.101	2.704	30.207	0.03
MS$_T$	0.219	24.921	69.226	0.139
F-test				
F_C	18.04	120.13	19.73	52.93
F_{tab}	3.35	3.35	3.35	3.35
H_0	False	False	False	False

Because null hypothesis was rejected, percent of PP fibers at first usage is a factor with a significant influence on nonwoven geotextiles main characteristics.

The reason for adding PP fibers to fibrous blends consists of improving the properties of nonwoven geotextiles and to diminish variability (CV,%). In *Figures 4, 5, 6 and 7* contain the variation graphs for thickness, bulk density, air permeability and puncture strength. It is clearly seen that, with one exception (bulk density), all experimental data variations are lower if more PP fibers at first usage are added to the fibrous blend. The explanation is that recycled fibers are physically damaged, shorter in length and with a high variation of properties compared to fibers at first usage, because they went through many processing stages before becoming part of nonwoven geotextiles.

By reducing the percent of PP fibers from 67% to 33% it was noticed a loss of 77.55% for puncture strength and 15.60% for thickness, but an increase of 25.15% for air permeability.
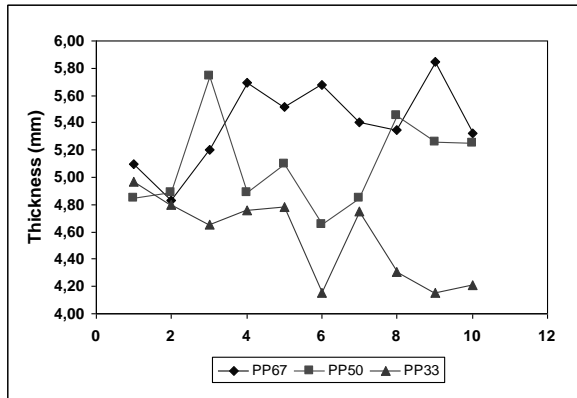

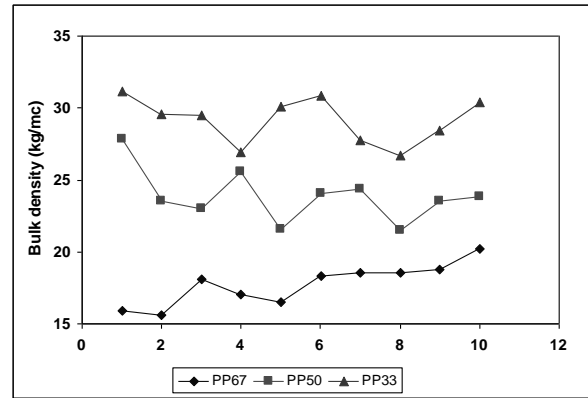**Figure 4.** Variation of thickness.

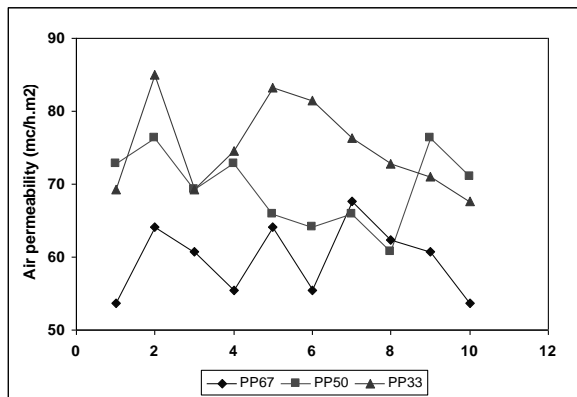**Figure 5.** Variation of bulk density.
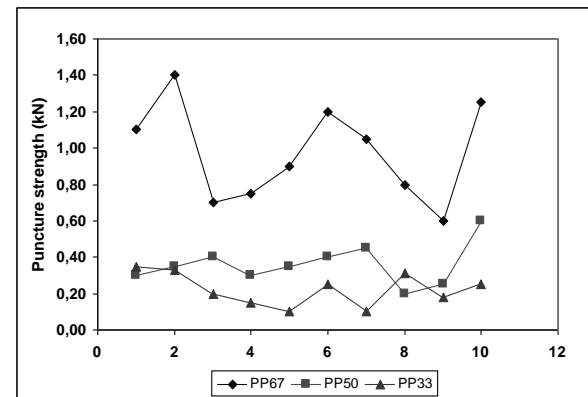

Figure 6. Variation of air permeability.

Figure 7. Variation of puncture strength.

Depending on geotextile destination it can be chosen one fibrous blend (PP67, PP50, PP33) that fits to the requirements at the optimum manufacturing costs. For example, a needle-punched geotextile for roads reinforcement can be produced from blend PP50: very good puncture strength (0.36 kN), good thickness (5.1mm), bulk density (24kg/m^3), specific weight (120g/m^2) and air permeability (70m^3/min.m^2).

5. Conclusions
Nonwoven geotextiles have different properties depending on their application. By introducing recycled fibers into the fibrous blends, the raw materials costs will be reduced in the conditions of producing high quality geotextiles.

The study confirms that it is possible to apply the *Circular Textiles Industry* concept in Romania by forming regional closed loop systems which re-use all types of textile materials and manufacture nonwoven geotextiles. Population and companies must be trained how to correctly collect the textile waste.

References
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[3]   * * * www.circle-economy.com *Accessed on 17th February 2016*

[4]   * * * www.marketsandmarkets.com *Accessed on 31st of January 2016*

[5]   * * * www.edana.org *Accessed on 15th of February 2016*