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Nonwoven Development by the Multilayer Structure

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***Abstract.** the main two directives of the European Commission (EC) has been regulating the automotive industry. The aforementioned directives and education of residents on environmental issues has created the need for new materials that have been produced from renewable resources and should be recycled at the end of product life cycle.*

The objective of this project is to develop a nonwoven materials (NWM) that would incorporate fibers of plants, which could be grown in Latvia because of suitable local climate conditions, for the use in automotive industry. Furthermore, inclusion of polymer fibers in the NWM will expand the areas of use of such material – the NWM can be transformed into a composite material by means of a thermal press.

Manufacturing process of NWM consist of structure modelling and material samples manufacturing. NWM samples production process to be carried out by fibers preparation, fibers mixing, formation by airlaid method, preparation of fiber webs for fixation with a mechanical needle punching method, mechanical fixation of fiber webs, preparation of fixed fiber webs for NWM manufacturing and manufacturing of NWM by mechanical needle punching method.

This article reflects the comparison of two compositions NMW (Polylactid (PLA) (60 wt%) and long flax fibres (40 wt%), and PLA (60 wt%) and technical hemp fibres (40 wt%)) with the same structure by visual appearance, geometrical parameters and tensile strength. The average surface density of hemp NWM varies in the range of 792.09 to 958,71 g·m^{-2}, thickness varies from 6.91 to 9.23 mm. Flax NWM average surface density is higher than hemp NWM and varies in range of 1,064 to 1,260 g·m^{-2}, thickness of the material varies from 12.62 to 15.54 mm. For comparison, the surface density of NWM currently used in automotive industry, depending on the use of the material, varies from 100 to 1,400 g·m^{-2}.

***Keywords:** hemp fibers, flax fibers, nonwovens.*

I. INTRODUCTION

The country, where people live, and the legislation of such country regulate the daily life of its residents to a great extent. Not only national legislation, but also the effective directives of the European Union (EU) are binding on the residents of the EU member states. Over the last years, two directives of the European Commission (EC) have been regulated the automotive industry: 2000/53/EC and 2005/64/EC. The first one regulates the proportional amount of details that must be made of recycled resources and the amount of details that could be recycled at the end of product life cycle. The second directive provides that the motor vehicle manufacturers must provide the EU institutions with information on the recycling methods of details used in vehicles. Both directives are based on reduced use of non-renewable resources and wider use of renewable resources.

The aforementioned directives and education of residents on environmental issues has created the need for new materials that have been produced from renewable resources and should be recycled at the end of product life cycle. The objective of this project is to develop a NWM that would incorporate fibres of plants, which could be grown in Latvia as a result of suitable local climate conditions, for the use in automotive industry. Furthermore, inclusion of polymer fibres in the composition of NWM will expand the areas of use of such material – the NWM can be transformed into a composite material by means of a thermal press. The use of a polymer of biological origin and uniting it with plant fibres allows to obtain a material that conforms to the conditions of sustainable environment management.

II. MATERIALS AND METHODS

Flax, hemp and PLA fibers have been used for the development of samples.

A. Flax fibers

Common flax or linseed (Linum usitatissimum L.) is an ancient agrotechnical culture, which has been cultivated in the territory of Latvia as well. Flax is an annual plant that has been cultivated for two principal crops: fiber and seed (i.e. oil linseed). A stalk of a long-stalk flax contains 20 – 30% of fibers. The composition of the fiber is significant for the plant because the principal component of cell membranes is cellulose, which ensures the strength of the fiber. Cellulose is not water-soluble. Cellulose accounts for an average of 60 – 80% of the total flax fiber mass, the rest of the mass consists of lignins, pectins, plant waxes and fats, various water-soluble substances and hygroscopic water. Cellulose, the chemical formula

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of which is $(C_6H_{10}O_5)$ n, is a natural polymer – a macromolecular substance with high degree of polymerisation (300 – 3,000).

The geometrical parameters of the flax fibers used for the research have been determined by laboratory methods: fiber fineness is 3.87 dtex, average length - 139.23 mm.

The average market price of long-fiber flax is approximately 1.39 EUR/kg [1].

B. Hemp fibers

Hemp (Cannabis sativa), like flax is an annual plant and a traditional agrotechnical culture in Europe and all regions of Latvia. Similarities between both plant cultures are observed, the structure of the fibers of both plants is in principle similar. Depending on the sort of hemp, the content of fiber in its stalk can reach 25 – 35%. Cellulose forms ~ 77% of the total mass of hemp fibers.

German company BaFa Badische Naturfaseraufbereitung GmbH, which is specialising in hemp fiber cultivation and processing, supplied the hemp fibers used for the development of samples. Company classifies the fibers used for the development of samples as technical fiber with product name Vliesfähige Faser VF6.

The average market price of technical hemp fibers is approximately 0.6 – 0.8 EUR/kg [2].

C. Polylactide fibers

PLA is a natural biopolymer [3], consisting of linear macromolecules with chains containing at least 85 wt% lactic acid esters that are obtained from naturally occurring sugars. The melting temperature thereof is at least 135 °C [4; 5]. PLA is a biodegradable and biologically compatible material that can be processed by using standard manufacturing devices. Depending on the service life of a product with embedded polymer, the time of polymer degradation can be controlled.

The PLA used in the samples has been supplied by the company Ingeo [6], which produces the polymer from corn starch. Sugars generate both principal components of the PLA polymer obtained from corn – carbon dioxide and water. Starch is transformed into glucose by means of fermentative hydrolysis. The glucose is fermented into lactic acid at almost neutral level of pH. The PLA polymer used in the samples has the shape of fibers. Their technical parameters are as follows - type: SLN 2660D, specification: 6.0 dx 64 mm x FB, fiber fineness: 6, 5 ± 0, 5 den, fiber length: 64 ± 4 mm.

The average market price of PLA fibers is 2.12 – 3,5 EUR/kg, for comparison, the price of PP, frequently used for NWM is approximately 1.61 - 1.82 EUR/kg [7].

D. Nonwoven manufacturing

NWM provides the possibility of reaching a textile material with wide functional properties: the porous structure of the material ensures thermal and sound insulation, as well as absorbing properties. These properties are especially significant for textile materials used in motor vehicle constructions.

Two types of NWM have been developed within the framework of this research: PLA fibers (60 wt%) mixed with long fibers of flax (40 wt%) and PLA fibers (60 wt%) mixed with technical fibers of hemp (40 wt%). The same principle of material structure development and manufacturing technology has been used in both NMW. Mechanical manufacturing method has been used for the creation of both NMW – needle punching. NMW structure has been demonstrated in Fig. 1, in accordance with which the total quantity of fibers is divided into five fiber layers. The three internal layers of fibers are similar in terms of their constituent components, fiber proportion and mass. Uniting these three layers into one would be more economically viable, however, the solution of 3 fiber layers was chosen due to the technological characteristics of the available equipment in order to obtain a material with as equal punch distribution (more homogeneous connection of fibers) as possible. The following operations have been included into the production process:

1. preparation of fibers for work (weighing of the required amount of fibers, loosening of fibers);
2. creation of fiber web layers;
3. punching of fiber web layers:
   a. preparation of fiber web layers for fixation (in order to reduce the number of punches during the production process and, to prepare three fiber web layers for fixation from five fiber web layers, by placing layers on top of each other);
   b. fixation of fiber web layers by needle punching;
   c. arranging of three fiber layers and preparation thereof for the production of NWM.

Production of NWM by means of needle punching method (needle punching of three fixed fiber web layers into a single material).

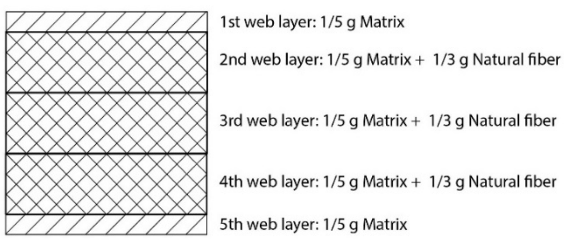

Fig. 1. Structure of nonwoven material.

The fibers were loosened, both types of fiber were mixed (by using the *airlaid* method) and fiber layers were created by using the same device – TRÜTZSCHLER CVT3 1200. In this device, the proportioned amounts of fibers were delivered from the fiber feed-in area via parallel horizontal rollers to the vertical vacuum cylinder, which is connected to the device. In the fiber layer, which was obtained in the cylinder, the fibers were dispersed in various, indefinite directions. During the NMW production process, the needle punching was performed in two phases. During the first of the phases the fiber layers were fixed and after the second punching phase the finished material was obtained. The same device has been used in both phases of punching: DILO LBM 6. This device has one needle board, which does the work by means of a downwards movement. In order to ensure the minimum number of punches during the production process of NWM, three fiber layers must be prepared for fixation from initially produced five fiber layers by placing one layer on top of another, see Fig. 2); The following sequence of operations has been observed during the first needle punching procedure:

1. the 1st fiber web layer was punched (PLA fiber layer) together with the 2nd fiber web layer (the layer, where plant fibers were mixed together with PLA fibers);
2. the 3rd fiber web layer was punched separately;
3. the 4th fiber web layer was punched (the layer, where plant fibers and PLA fibers were mixed) together with the 5th fiber web layer (PLA fiber layer).

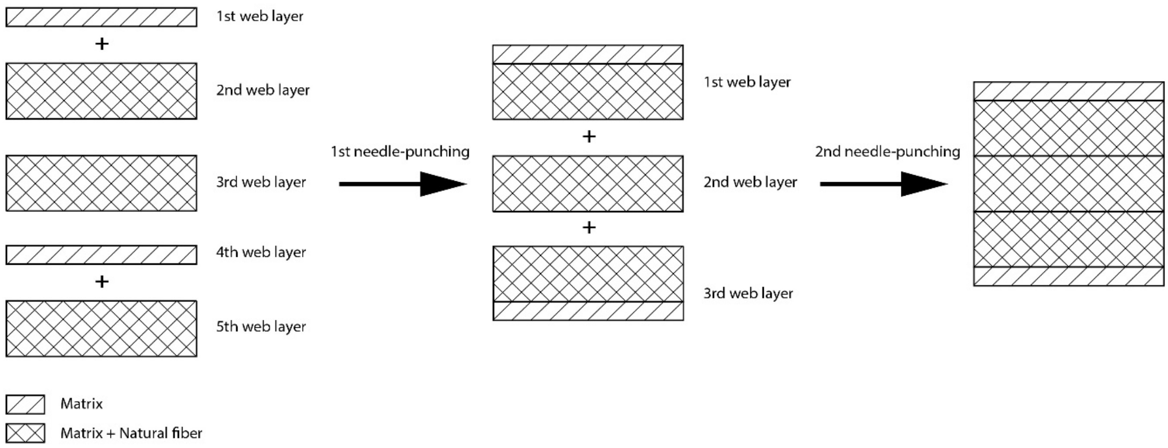

Fig. 2. Needle punching in the manufacturing process of nonwoven material process

The fiber web layers, where two fiber layers were fixed together, were inserted into the needle-punching device with the layer of PLA fibers facing upwards, closer to the needle board. Before the second punching phase, the three previously fixed fiber layers were arranged and placed in accordance with the production scheme of NWM (see Fig. 1 and Fig 2).

III. RESULTS AND DISCUSSION

Different number of samples has been obtained from the both NWM materials within the framework of the research: 5 samples of PLA and hemp NWM (samples labelled with Latin alphabet letters A, B, C, D and E) and 3 samples of PLA and flax NWM (samples labelled with Latin alphabet letters A, B and C). 6 stripes of NWM sized 50 x 300 mm have been cut out of each sample, of which 3 stripes (Fig. 3) from each sample (in the event of Sample D - 1 stripe have been used for the research of NWM. Among the researched samples, the stripes labelled with Latin block capitals and numbers 1 and 3 have been cut out along the direction of operation of the needle punching device, or so called in the machine direction. The sheets that have been labelled with Latin block capitals and number 5 have been cut in the cross-machine direction. Each of the stripes has the same length and width. The average thickness values between both compositions of NWM differed by approximately 40%, hemp technical fiber containing material is thinner and its thickness varies from 6.91 to 9.23 mm. The thickness of flax fiber containing material ranges from 12.62 to 15.54 mm. The thickness of the produced material samples is directly linked with the quality of fibers binding.

The NWM spicemen strips containing flax fiber are visually lighter - PLA fibers dominate on their surface and the fact that the thickness thereof exceeds that of hemp fiber containing NWM is visible without using technical metering equipment (Fig. 3). The natural colour of hemp fibers is visible in the surface of hemp fiber containing strips, along with the white colour of PLA fibers. Upon the analysis of the obtained breaking strength results and visual appearance of the materials, it can be concluded that the surface density of the material is the factor that mostly affects the durability parameters of the NWM material, including the stretching of the material. The surface density of the hemp containing NWM varies from 792 to 959 $g \cdot m^{-2}$, the surface density of the flax containing NWM is higher and varies from 1,064 to 1,260 $g \cdot m^{-2}$. For comparison, the surface density of NWM materials currently used in automotive industry, depending on the use of the material, varies from 100 to 1,400 $g \cdot m^{-2}$ [8].

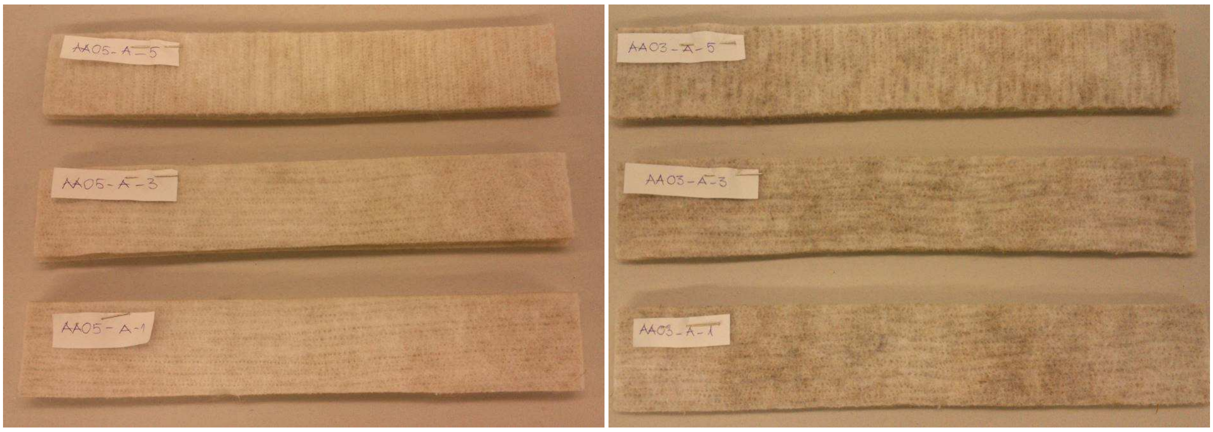

Fig. 3. NWM sample stripes, the lower stripe No. 1 and the medium stripe No. 3 have been cut in the machine direction (0°), the upper stripe No. 5 has been cut in the cross-machine direction (90°): flax fiber containing NWM sample A is on the left, hemp fiber containing NWM sample A is on the right.

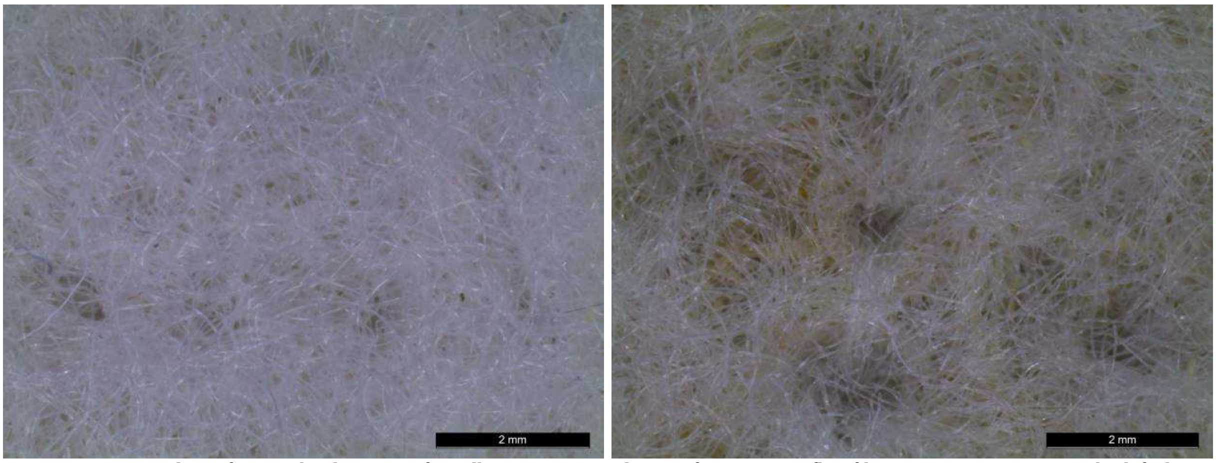

Fig. 4. NWM sample surface in the direction of needle impact, optical magnification 16x: flax fiber containing NWM on the left, hemp technical fiber containing NWM on the right.

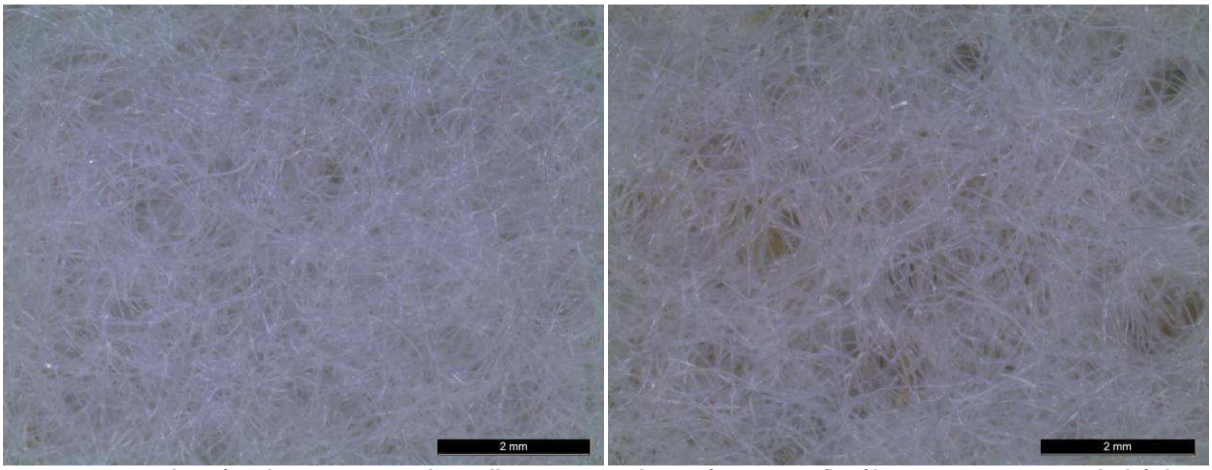

Fig. 5. NWM sample surface that is opposite to the needle impact, optical magnification 16x: flax fiber containing NWM on the left, hemp technical fiber containing NWM on the right.

Upon using the optical microscope for the observation of the samples of NWM materials of both compositions, the traces left by needle punching device are visible as holes of regular shape that recur over regular interval. They are better visualised in the surface of the material that has been directly subject to the impact of the needles (Fig. 4 and Fig 5). After the punching process it can be concluded that more homogeneous binding of fibers (the fact must be linked with the tighter binding between PLA fiber web layer and mixed fiber web layer (natural and PLA fibers)) has occurred in hemp fiber containing NWM samples. The colour of material isn't as pronouncedly white as in the NWM containing flax fibers. Poorer fiber binding in the flax containing NWM is evidenced by poorly visible traces of needle punches in the surface of the material that is opposite to the work direction of the needles. Poorer binding of flax fibers containing NWM is visible even without technical aids and can be checked by trying to separate the strips of samples in the external surface of fiber layer with hands – easily separable.

Table I
PLA and Hemp NWM, PLA and Flax NWM tensile test results

NMW	Sample code	Strip code	Width	Length	Average thickness	Sample section area	Surface density (mA)	Ultimate tensile strength (F_{max})	Breaking load (F_{bruch})	Tensile strength elongation (e F_{max})	Elongation after breaking load (e Bruch)	Sample after testing
			mm	**mm**	**mm**	**mm²**	**$g \cdot m^{-2}$**	**MPa**	**MPa**	**%**	**%**	
PLA and Hemp	AA03_A	A1	50	300	8,87	443,65	894,69	0,05	0,01	31,79	42,20	Not failed
	AA03_A	A3	50	300	8,46	422,83	918,05	0,06	0,01	28,68	36,28	Not failed
	AA03_A	A5	50	300	8,69	434,70	848,95	0,05	0,01	40,24	47,34	Not failed
	AA03_B	B1	50	300	9,23	461,25	891,19	0,05	0,01	35,88	45,39	Not failed
	AA03_B	B3	50	300	8,21	410,43	873,48	0,06	0,01	29,43	37,99	Not failed
	AA03_B	B5	50	300	7,63	381,45	792,09	0,05	0,01	41,64	50,67	Not failed
	AA03_C	C1	50	300	8,81	440,45	958,71	0,07	0,02	37,08	46,19	Not failed
	AA03_C	C3	50	300	8,78	439,05	923,72	0,06	0,01	31,66	39,14	Not failed
	AA03_C	C5	50	300	8,70	434,95	892,47	0,05	0,01	45,63	51,56	Not failed
	AA03_D	D5	50	300	8,30	415,00	796,67	0,04	0,01	30,69	42,39	Not failed
	AA03_E	E1	50	300	7,02	350,90	891,31	0,10	0,02	35,63	46,24	Not failed
	AA03_E	E3	50	300	7,17	358,70	848,46	0,09	0,02	39,40	45,07	Not failed
	AA03_E	E5	50	300	6,91	345,55	858,93	0,08	0,02	35,69	47,10	Not failed
PLA and flax	AA05_A	A1	50	300	14,58	728,78	1260,51	0,03	0,01	56,24	68,54	Not failed
	AA05_A	A3	50	300	12,62	630,88	1232,53	0,04	0,01	55,54	67,61	Not failed
	AA05_A	A5	50	300	13,53	434,70	1132,70	0,05	0,01	39,88	47,02	Not failed
	AA05_B	B1	50	300	13,15	657,48	1221,27	0,03	0,01	56,50	67,74	Not failed
	AA05_B	B3	50	300	14,68	733,98	1222,01	0,03	0,01	58,96	67,10	Not failed
	AA05_B	B5	50	300	13,96	698,10	1065,74	0,03	0,01	42,40	52,08	Not failed
	AA03_C	C1	50	300	15,54	776,88	1180,77	0,04	0,01	48,99	59,55	Not failed
	AA03_C	C3	50	300	14,35	717,48	1228,77	0,04	0,01	55,79	66,59	Not failed
	AA03_C	C5	50	300	14,72	736,15	1138,87	0,03	0,01	46,59	55,35	Not failed

All tensile test results of NWM are presented in Table 1. Ultimate tensile strength of hemp fibers NWM samples ranges from 0.04 to 0.10MPa and material elongation ranges from 29 to 46%. Tensile strength test results of hemp fibers NWM are higher and elongation amplitude is lower than flax fibers NWM - tensile strength ranges from 0.03 to 0.05 MPa, material elongation ranges from 40 to 59%.

IV. CONCLUSIONS

As a result of the research a plant fiber and biopolymer NWM structure has been created. A total of two NWM using plant fibers of traditional for the territory of the Republic of Latvia, but nowadays uncommon flax and hemp agriculture, have been developed and mutually compared.

The NWM samples obtained during the research, according to the colour of the fibers used for manufacturing, are light in colour – due to white-coloured PLA fibers situated in the outer surfaces, the samples are lighter in colour than flax (in PLA and flax fiber samples) and hemp (in PLA and hemp fiber samples) fiber colour. Although the same process and devices have been used for the manufacturing of both materials, better binding of fibers has been observed in hemp fiber containing material samples. Due to better binding of fiber the hemp NWM samples are thinner, ultimate tensile strength have higer while material elongation have lower in comparison with flax NWM of the same structure. The average surface density of both developed NWM (hemp fiber containing material 792.09 to 958,71 $g \cdot m^{-2}$ and flax fiber containing material 1,064 to 1,260 $g \cdot m^{-2}$) falls within the amplitude of surface density of NWM that are most frequently used in automotive industry (100-1,400 $g \cdot m^{-2}$). In order to find the best application for the NVM developed in this project, material wear, sound absorption and acoustic tests of the samples must be performed in addition to the tests that have already been implemented.

The comparison of PLA costs with other polymers shows that, for instance, PP, PLA fibers are more expensive. Without the further objective of reprocessing both NWM into composite materials, the use of PLA is not economically viable.

V. ACKNOWLEGEMENTS

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