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COMPOSITE MATERIALS BASED ON NATURAL AND RECYCLED FIBERS FOR AUTOMOTIVE INDUSTRY

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SUMMARY: The paper presents the research results on recycling of wastes saturated with phenolic resin and their use in production of elements for automotive industry.

The paper presents the structure changes of working element of tearing device adopted to that kind of production. The composition of recycled raw materials mixture was established experimentally depending on the direction of application. The natural fibers (flax and hemp) were tested for application as reinforcement material in elements manufactured from recycled fibers.

The conducted research resulted in modernization of the tearing device which enabled recycling of needle-punched and resin-saturated wastes used in automotive industry. The trials allowed also for verification of possibility of natural fibers (flax and hemp) application as reinforcement for the composite materials produced from recycled materials.

INTRODUCTION

In European countries, cars and trucks carry 80% of people and 50% of goods. According to the data of European Union, the number of cars increased within last 20 years, from 70 million to approximately 142 million in 1992. The biggest car manufacturers in USA and Japan produce 7 million cars per annum each, while in European Union about 8 million cars. Such huge number of newly produced cars requires a constant supply of raw materials necessary for production. Therefore, recycling of worn out cars or car parts must become a source of raw materials that will allow recovering different materials.

The estimates showed that in 1995 the number of cars in the USA and Japan and EU totaled at 315 million. Out of this amount about 33 – 35 million of cars are scrapped every year. It is estimated that each manufactured car will have to be scraped after on average 15 years and recycled. This also makes some problems connected with wasting of worn out vehicles. Each new car will have to be recycled after on average 15 years. In 1993, in countries of EU, 8 million cars were withdrawn from circulation, approximately 40% of this amount was exported to other countries. Remaining 60% was recycled.

The worn out and recycled may recycle up to 100% of steel, 90% of non-ferrous metals and 25 – 35% remaining materials. It is planned that 85% of materials will be recycled and recovered from each scraped car by 2002 and 95% after 2015.

The growing population and economical growth cause the necessity of care for minimum wastes and energy consumption. This is the only way to rebuild the natural resources and stop the degradation of natural environment. The requirements for cars grow continuously. Cars must be safe, reliable, durable, inexpensive and economical in the stage of production, use and disposal. The possibility of recovery of parts and materials begins to play a considerable role in designing of a car of the future. Solid wastes left from cars contribute 1.5% to communal wastes. The cost of wastes disposal grew 3 – 4 times in 1980s. Therefore, the full recycling of materials may become a major element of cost reduction in car manufacturing.

In the future, the following pro-environmental requirements will be taken into account in car designing:

- marking of all plastic parts,
- joints easy for dismounting,
- economic management of materials and energy,
- limitation of amounts of materials used,
- simplification of systems containing fluids,
- unification of electric parts and systems.

One of the most important trends in designing of cars, no matter what propulsion system will be used in the future, electric one or based on combustible fuels, is to develop the technology and materials allowing for production of ease-to-dismount car body elements. Decreasing the car weight by each 1 kg causes reduction of fuel consumption by 0.05 – 0.1 dm^3/100 km. Replacement of steel in a frame of seat of a Mercedes with a thermoplastic polymer reinforced with glass or natural fiber, decreased the weight of the frame by 4 kg. No negative effect on the stiffness of the frame, decreasing the total costs of car manufacturing was observed. The polymers reinforced with fibers – composites, already in the stage of production require less energy than metals. Moreover, in the processes of controlled combustion up to 30% of energy concentrated in composites can be recovered. A well-designed car, containing a lot of composite materials (lightweight, durable and recyclable), brings fewer burdens to the environment than traditional, heavy limousine. The nature teaches us that a waste material can be used as a raw material and effective and environmental friendly car industry should follow the nature.

The Recycling of materials used for construction of vehicles allows to avoid wasting of processed materials, which are thrown away together with energy that are concentrated in them. Implementation of more expensive technology, decreasing the amounts of wastes and allowing for multiple use of a product or material is in final account cheaper than collecting, transporting and neutralizing of wastes.

In time of shrinking natural resources and very unfavorable CO_2 balance a bigger and bigger importance of renewable resources is observed, including fibrous plants. Flax and hemp, traditionally used as textile raw material, at the beginning of 21st century experience their renaissance. They find application in the fields where they had not belonged up to very recent time. The example of such field is an automotive industry. Since 1998, the company Opel has been using a mixture of flax and polypropylene fiber in a form of composite for covering car doors from the inside. Applied natural fibers must, however, ensure high quality, and avoid performance of disadvantages connected with their natural properties like for instance smell or mildew.

For a very long time the structure elements in car manufacture were polymers reinforced with fibers. Such combination, however, is connected with some problems like big weight of an element, problems with recycling and bad effect on human body during mechanical processing of details (glass fiber dust evolving during processing may cause allergy). Unlike the material described above, the elements reinforced with natural fibers offer technological, ecological and economical advantages.

The most important factors for performance of polymers reinforced with natural fibers are fiber strength, its availability and quality. The research conducted by Daimler Chrysler confirmed the high usability of flax and hemp among domestic and curaua and sisal among tropical fibers for production of composites. The elements reinforced with natural fibers are produced by two basic technologies:

- low pressure spraying, for bulk, thin elements, and
- injection, for more complex geometrical shapes.

Each method requires preparation of natural non-wovens especially in terms of elimination of odor emission, reduction of water absorbency and improvement of impact resistance.

Due to utilization of flax and hemp fibers as the reinforcement of composites during the production of a composite, fibers are subjected to high temperature. Hence, a question of their thermal stability arises. The research conducted by Kathleen Van de Velde and Edie Beatens showed that long expositions to high temperatures have detrimental effect on mechanical properties (fibers become brittle). Therefore, it is very important to produce composites by a short technological process, because the safe exposition to 240 °C is only 4 minutes.

The polymers reinforced with natural fibers can be used for production elements of interior and exterior structure of a vehicle, provided that an accurate impregnation of fibers against water is secured. Application of natural fibers instead of glass fibers gives great ecological advantages with comparable technological performance of a composite. Depending on the kind of structure element and used combination of fiber, the reduction of costs of materials and better recycling performance can be achieved.

DESCRIPTION OF WASTES SUBJECTED TO RECYCLING

The material to be recycled are wastes of non-wovens resulting from torn wastes of cotton cloth bound with thermosetting phenolic resin and scraps of hard, needle-punched polyester and polypropylene fibers treated with resin. The hardness of the wastes depends on the content of resin and degree of compression. They can be very soft, very hard or mixed. The scraps of polyester-polypropylene non-woven treated with resin are ductile are highly compacted and durable. Very important is characterization of fibers contained in wastes. The non-woven from torn cotton material contains different short fibers, which maximally are 40 mm long, while treated with resin non-wovens – fibers about 60 mm in length. The content of resin in the first kind of non-woven is 36%, while in the thermosetting resin – 30%.

THE PROTOTYPE OF A TEARING UNIT

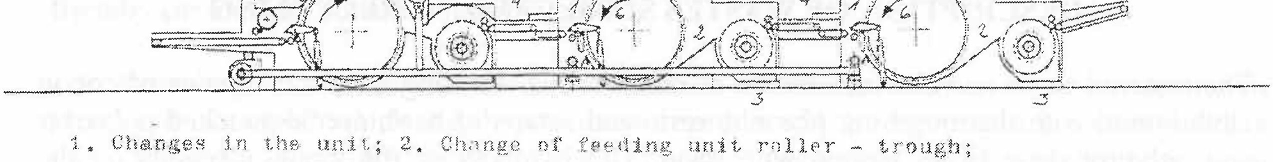
A tearing machine type AC 30/3 was used for tearing wastes emerging in production of elements made of NON-WOVEN. The machine was modernized in order to ensure proper technological parameters.

The most important changes introduced in a typical tearing unit:

1. Infinitely variable adjustment of feeding and delivery unit at stable revolutions of tearing cylinder
2. Change in design of bearings of feeding and delivery conveyor
3. Change in design of bearings of feeding cylinders (fluted ones)
4. Change of tearing cylinder covering and selection of proper pinning
5. Change of lubrication systems of working sub-assemblies bearings
6. Introduction of troughs instead of bottom inserting cylinders
7. Elimination of upper grooved feeding cylinder and replacing it with a cylinder with a saw wire
8. Change of operation direction of tearing cylinders
9. Elimination of upper lids and accompanying devices
10. Introduction of new chutes for elimination of untorn wastes and metallic impurities
11. Change of the position of a conveyor eliminating untorn wastes.

Positions 6 – 11 refer to modernization of tearing sections No. II and III. The tearing unit modernized in this way, Fig. 1, is a basic device in discussed here technology of tearing wastes emerging in production of non-wovens.

Introduced technical changes into typical tearing unit AC 30/3 allows for improvement of qualitative parameters of operation of a new unit and improvement of quality of obtained torn cloth.



1. Changes in the unit; 2. Change of feeding unit roller - trough;
3. Change of the chute structure; 4. Change of the position of devices removing untorn wastes; 5. Change of conveyors bearings; 6. Change of tearing cylinder covering;
7. Change of operation direction

Working width of tearing unit 1000 mm /2000 mm/
Width with dust collectors and shields ok. 4000 mm

Figure 1 Modernized tearing machine

The target technological effects of non-woven tearing were obtained through proper setting of working elements of tearing machine. Selecting correct speeds, pinning and optimal distances between elements are very important for the effect of tearing and quality of torn cloth.

The optimum parameters of tearing unit are given in Table 1.

Table 1. Technological parameters of the tearing unit

Sub-assembly No.	Parameter	Working element	Unit	Parameter value
I	Speed	Feeding unit	M/min	1,92
		Tearing cylinder	Rev./min	450
		Delivery unit	M/min	3,00
	Pinning	Tearing cylinder I	Rows x # of pins	8 x 58
	Distance	Feeding rollers – tearing cylinder I	mm	3,00
II	Speed	Feeding unit	M/min	3,52
		Tearing cylinder	Rev./min	450
		Delivery unit	M/min	3,18
	Pinning	Tearing cylinder II	Rows x # of pins	9 x 74
	Distance	trough – Tearing cylinder II	mm	2,00
III	Speed	Feeding unit	M/min	3,60
		Tearing cylinder	Rev./min	450
		Delivery unit	M/min	4,26
	Pinning	Tearing cylinder III	Rows x # of pins	9 x 74
	Distance	trough – Tearing cylinder III	mm	1,00

SELECTION OF WASTE MIXTURE COMPONENTS FOR TEARING

In spite of the character of wastes such as scraps of strongly needle-punched and saturated with resin polyester-polypropylene non-wovens and NON-WOVEN wastes, the process of tearing is rather a difficult operation. Expected parameters of torn cloth – fiber length over 10 mm and dust content below 10% – limit considerably the extent of mechanical processing. The content of resin and degree of compression may result in very hard or mixed wastes. Therefore, there is a necessity, confirmed by studies, for forming of mixtures. The principles of manipulation and composing of mixtures must ensure the optimal process of tearing and the best qualitative parameters of obtained torn cloth.

Depending on further application of non-woven it can be manufactured from different mixtures of materials:

I	Scraps of cotton clothes	35%
	Scraps of needle-punched non-wovens	30%
	Wastes of highly cross-linked non-wovens	35%
II	Scraps of cotton clothes	40%
	Scraps of needle-punched non-wovens	40%
	Wastes of highly cross-linked non-wovens	20%

The composition "I" is recommended for manufacture of non-wovens used for moulding of flat, highly pressed details, while the composition "II" for three-dimensional elements.

THE RESULTS OF WASTE TEARING

The main goal of trials with waste tearing was obtaining fibers from recycled torn cloth, which could be reused in production of non-wovens. Resulting parameters can be met by a torn cloth that contains fibers about 10 mm long and below 10% of dust.

In a trial where the composition "I" was torn, the torn cloth containing fibers with mean length of 11.3 mm and about 5% of dust were obtained (Table 2). This torn cloth can be used for production of non-wovens for moulding flat, highly pressed details. In the second trial, the tearing of wastes produced torn cloth with the average length of fibers on the level of 12.4 mm and 4% of dust content. In this trial no untorn fractions were found. Obtained parameters favored this material to be used in production of needle-punched non-wovens (Table 2).

Table 2. Metrological parameters of torn cloth.

Trial No.	Divisibility		Fiber length fraction composition %						Mean length mm	Mass fraction	
	Nm	Tex	0 – 2	2 – 6	6 – 10	10 – 15	15 – 25	25 – 35		Torn	Untorn
I	1333	0,75	5,0	15,0	35,0	23,5	13,5	8,0	11,3	93,2	6,8
II	1347	0,74	4,4	12,2	30,5	26,8	17,0	9,0	12,4	100,0	0

PARAMETERS OF TEARING

The following parameters of tearing on tearing unit, depending on composition of applied mixture, were obtained:

		Value
Raw material composition variant I	1. tearing unit efficiency	300 kg/h
	2. losses in cutting	2,0%
	3. losses in tearing	13%
	4. average length of fibers in tearing machine	10 – 11 mm
	5. dust content	5%
Raw material composition variant II	1. tearing unit efficiency	350 kg/h
	2. losses in cutting	2,0%
	3. losses in tearing	5,0%
	4. average length of fibers in tearing machine	11 – 12 mm
	5. dust content	4,0%

III Qualitative requirements of torn cloth produced by tearing unit

The following qualitative requirements are necessary for production of non-wovens from recycled torn fibers:

1. fibers of torn cloth over 1 mm in length
2. dust content below 10%

TRIALS ON APPLICATION OF FLAX AND HEMP FIBER FOR MANUFACTURING OF NON-WOVENS CONTAINING RECYCLED FIBER

In trials with production of non-wovens, flax and hemp fiber in concentration of 20 and 50% was used.

The basic raw material for trials was short waste fiber from production of long scutched fiber. Obtained in this process flax or hemp fiber is highly contaminated and requires mechanical cleaning. This operation was carried out on the flax and hemp homomorphic-fiber-producing unit.

The unit contains the following working sections:

- feeding table
- breaking machine I
- breaking machine II
- lower shaker I
- breaking machine III
- breaking machine IV
- lower shaker II
- breaking machine V
- three-section scutcher
- lower shaker III
- travelling lattice
- lower shaker IV
- delivery table.

The aim of this unit is to separate shive and other impurities from the fiber by cyclic operations of breaking, shaking and scutching of raw material.

Obtained flax or hemp fiber was further subjected for processing on Russian tearing-blending apparatus P 150 L.

The processing of both flax and hemp fibers was conducted with the following parameters:

- efficiency of the apparatus 480 kg/h
- linear density of resulting sliver 150 ktex
- losses in processing 8%

The next step was carding of obtained flax or hemp sliver on a carding machine Cz-600 L aiming in further cleaning and shortening of fiber.

The following parameters of carding process were applied:

- pinning set 4

- losses in process 20%
- efficiency 100 kg/h

The qualitative parameters of hemp and flax fiber prepared for trials are given in Table 4.

Table 4 The qualitative parameters of hemp and flax fiber used for production of non-woven

Fiber	Divisibility		Impurities	Length composition (staple), % of particular fiber length [mm]							Mean length [mm]
	[Nm]	[Tex]	[%]	0-20	20-50	50-100	100-150	150-200	200-250	250-300	
Flax	305,8	3,27	8,6	5,0	30,7	33,4	19,7	7,2	4,0	–	79,6
Hemp	142,8	7,0	13,8	0,4	17,1	29,8	27,6	14,7	5,6	4,8	114,2

Trials were conducted on the unit for production of non-wovens that allows to produce a wide range of non-wovens formed form textile raw materials and thermo-shrinking and thermoplastic polymers bonded with special thermosetting resins. The unit contained the following machines and devices:

- feeder
- aerodynamic carding machine
- scales
- furnace (drier)
- double cylinder tearing device
- cutter
- spreading machine

The trials conducted with flax and hemp fiber in combinations containing 20% and 50% of these fibers resulted in about 400 elements measuring 1020 x 830 mm and basis weight 700 g/m^2.

The production trials with non-woven containing flax and hemp fiber in proportion 20% and 50% were carried out with no problems. No interference in technological process was observed.

Obtained efficiency – 600 kg/h – was like efficiency in standard production of non-wovens.

The results of analyses of non-woven samples are presented in Table 5. The samples of manufactured non-woven containing 20% and 50% of flax fiber, the same proportion of hemp fiber and standard NON-WOVEN non-woven were used for trials. Obtained results in respect of weight, thickness, strength and fiber sedimentation were compared with requirements of FIAT standard.

CONCLUSIONS

1. Modernization changes introduced to the tearing unit allowed for recycling of needle-punched saturated with resin non-woven wastes in automotive industry.

Table 5. Qualitative parameters of tested non-woven samples

Sample	Tested parameter	Parameter value	Standard value
Standard non-woven	Weight [g]	796,0	700,0 (+10%; -0%)
	Thickness [mm]	14,7	12,0 (+3; -0)
	Longitudinal tenacity [N]	59,1	50,0
	Cross tenacity [N]	62,4	60,0
	Permanent sedimentation	24,8	≤ 25,0
Non-woven with 20% of flax fiber	Weight [g]	765,2	700,0 (+10%; -0%)
	Thickness [mm]	13,1	12,0 (+3; -0)
	Longitudinal tenacity [N]	59,7	50,0
	Cross tenacity [N]	65,1	60,0
	Permanent sedimentation	20,5	≤ 25,0
Non-woven with 50% of flax fiber	Weight [g]	63,1	700,0 (+10%; -0%)
	Thickness [mm]	14,0	12,0 (+3; -0)
	Longitudinal tenacity [N]	56,3	50,0
	Cross tenacity [N]	62,5	60,0
	Permanent sedimentation	16,3	≤ 25,0
Non-woven with 20% of hemp fiber	Weight [g]	780,1	700,0 (+10%; -0%)
	Thickness [mm]	14,8	12,0 (+3; -0)
	Longitudinal tenacity [N]	50,0	50,0
	Cross tenacity [N]	65,6	60,0
	Permanent sedimentation	24,2	≤ 25,0
Non-woven with 50% of flax fiber	Weight [g]	702,1	700,0 (+10%; -0%)
	Thickness [mm]	12,5	12,0 (+3; -0)
	Longitudinal tenacity [N]	51,3	50,0
	Cross tenacity [N]	65,6	60,0
	Permanent sedimentation	14,8	≤ 25,0

2. For better tearing and smooth operation the recycling of resin saturated non-woven wastes should be carried out in blend with other raw materials.
3. Obtained results, in respect of the quality of torn cloth from recycling, applying optimal parameters of tearing unit, fully meet requirements of reuse in production of non-wovens.
4. Recycling of resins saturated non-woven wastes and their reuse in production to the grate extent reduces costs and brings economical effects for the company.
5. Natural vegetable fibers, obtained from such plants as flax, hemp, cotton, jute, sisal, coir, etc. are an excellent source of reinforcing material for composites.
6. Production of composite materials reinforced with natural fibers has a beneficial impact on:
   - increase of farm productivity
   - high productivity of fiber plants
   - increase of employment in processing industry
   - environmental protection – cultivation of fiber plants on degraded areas
   - reduction of prices for composite materials
7. The composites reinforced with natural vegetable fibers show high strength, higher elasticity, are biodegradable and bring beneficial economical effects.

8. Manufactured resin saturated non-wovens containing flax and hemp fibers met requirements set in FIAT standard. In some cases the properties were even better that specified in the standard.

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