Superior Machining of Waste Composite Material with Rubber Matrix

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The superior machining of waste involves their reuse as raw material for new products. In the research there was aimed to improve the known technological process to reduce costs and increase productivity. Thus, the process was redesigned by introducing new technologies related to shredding of waste respectively de-vulcanization in autoclaves. Shredding technological process has been redesigned by using shredding tools, ultrasonic activated in order to increase productivity, durability of these tools respectively the decrease of energy consumption. There were also conducted researches on the autoclave vacuum after rubber de-vulcanization which allows an increase of reclaimed rubber qualities.

Keywords: composite waste machining, rubber, ultrasound, de-vulcanization

Due to technological difficulties encountered in processing of waste of composite materials with rubber matrix, currently less than 10 % of these higher capitalized and transformed into a new product. In the category of waste of with composite materials rubber matrix enter tires, conveyor belts, but the greatest proportion is represented by tires. The quantities of tires that should be superior valued worldwide are very high so it should be valued about 10 billion used tires each year. In these circumstances the question for technical solutions enabling the designing of a technological process of superior processing of wastes of composite material with rubber matrix [1]. Thus, from the analysis of technological processes of capitalization of waste from composite materials with rubber matrix was found as a first step in the technological process is the shredding of wastes, and it involves a high consumption of energy and materials and at the same time a technological operation with low productivity [2]. This is caused by the fact that great efforts are needed during shred due to high mechanical characteristics of composite materials such as are the tires which shows in general in the bead area reinforcing filler, metal insertion type. In these circumstances, the shredding process is dynamic with the emergence of vibrations and shredding forces vary around an average. To reintroduce in production the rubber from wastes from composite material another very important stage is the process of de-vulcanization. By applying de-vulcanization is obtained reclaimed rubber, and its distribution in discarded composite materials is presented in table 1 [3].

Selecting the type and proportions used in the manufacture of certain products, is done on an experimental basis depending on the requirements imposed by the finished product. It is appropriate that for each specific case there should be consulted the supplier specifications on qualitative indicators of the regenerated rubber provided. The results obtained with regenerated rubber provided by a certain manufacturer cannot be extended unconditionally and changing the provider requires re-verification of potential use. In general, however, regenerated rubber of the tire is, perhaps, the assortment produced in the largest quantities and widely used in a wide variety of products.

Regenerated rubber from the shell or inner tubes is preferred for dispersions and adhesives. Cheap types of regenerated rubber are introduced, generally, in the recipes of trough rubber articles in terms of performance and appearance. The types of special rubbers are introduced, usually in the same type of polymer compositions. There are some applications where the types of regenerated rubber made from special rubber are used successfully in general rubber compositions. As shown reclaimed rubber has found wide application in making various rubber products with great success by substituting new rubber made from original raw materials. Areas of use can be extended to non-traditional consumers of reclaimed rubber that can achieve by these important technical and economic advantages.

In terms of recovery and regeneration of waste rubber, in recent years, various technologies have been developed and numerous equipment and technology manufactured to recover the rational use of waste rubber. Thus, steel wire cord obtained by magnetic sorting is a quality raw material for obtaining steel cord, silk waste can be recycled in light industry and rubber granules can be used after size separation, to manufacture isolated bands, insulation layers of special buildings as an ingredient for obtaining special concrete or as a constituent in the manufacture of asphalt roads to give the necessary flexibility [4, 5].

The technological flow used most often in the recovery of rubber waste includes the following, (fig. 1) [6].

Fields of use	Quantity used [%]
Tires	55
Technical pressed articles	19
Conveyor belts, belts, hoses	7
Ebonite products	6
Fittings for installations and constructions, household products, dispersions, adhesives, footwear,	13

Table 1
A DISTRIBUTION OF RECLAIMED RUBBER ACCORDING TO THE FIELDS OF USE

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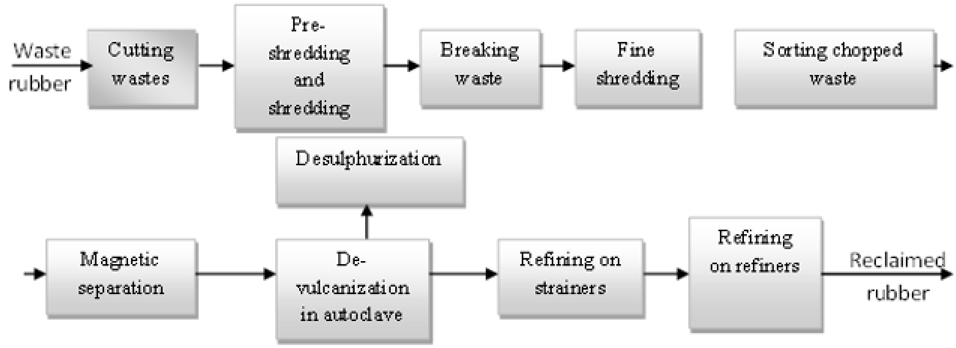

Fig.1. Classic process flow diagram for obtaining reclaimed rubber

Experimental part

The application of ultrasound in shredding process of waste from composite materials with rubber matrix

Thus, to increase technical and economic performance of tire shredding process was mainly aimed the reducing of the energy consumption, increase durability of tools and improve the productivity of the processing. In this respect it was examined the possibility of using tools, ultrasonically activated in the process of shredding. This solution was analyzed considering the effects of ultrasound in solid and the realized researches in the domain of use of ultrasound in the machining processes through splinting, because the shredding of waste of composites with rubber matrix is very similar to the machining processes through splinting [7, 8].

So, the theoretical and experimental studies on the application of high frequency oscillations for cutting have covered the field of their own frequencies ν = 2 - 18 kHz, for a vibrating movement with ν=20 kHz practically achieving the flattening of the variation curve y(t) for proper frequencies lower than 7.2 kHz. It has been noticed that for ν_n, lowering from 18 to 13 kHz, the amplitude of radial movement y decreased significantly and for the further decrease of proper frequencies n_n, up to 7.2 or 5.7 kHz, movement chart flattened, becoming practically parallel to the x-coordinate axis [9, 10].

In the case of processing made with ultrasound oscillations, the tool undergoes a dynamic load of variable sign, in which case the chip formation process develops easier, cutting forces decrease, and therefore the actual power as well. For the analysis of the ultrasound energy influence on the cutting tool we define the force coefficient K_{Fi} as the ratio between the size of the cutting force without ultrasound activation F_i and the size of the force with ultrasound activation $F_{i\,US}$ (i = x, y, z) that is:

$$K_{Fi} = \frac{F_i}{F_{ius}} \quad (1)$$

Experimental researches lead to a variation of this coefficient under the form:

$$K_{Fi} = C_{Fi} \cdot v_{max}^{x} \quad (2)$$

where: C_{Fi} and k are experimentally determined constants.

Taking into consideration the variation of the cutting force size and the actual cutting speed, the average cutting power consumed in the process will also change. Taking into consideration that in the classical processing, the actual power is P = $F_c \times v$, in the activation with tangential ultrasound oscillations, the power P_{us} will be

$$P_{us} = F_{c\,us} \cdot v \cdot \cos(F_c, v) + F_{p\,us} \cdot v$$
$$\cdot \sin(F_c, v) = F_{c\,us} \cdot v + F_{p\,us} \cdot v(t) \quad (3)$$

In order to determine the value of the average sizes of consumed power, we introduce power coefficient K_p, given by the relation:

$$K_P = \frac{P}{P_{us}} \quad (4)$$

For various values of the actual processing average speed, this coefficient has various expressions depending on the type of ultrasound oscillations, as follows:

- for the application of oscillations on tangential direction, it has the expression:

$$K_{Ptg} = \frac{K_{F_z}}{1+v_{med}} = C_1 \frac{v_{med}^{\kappa_1}}{1+v_{med}}; v_{med} = \frac{\kappa_1}{1-\kappa_1} \quad (5)$$

where: C_1, k_1 are experimentally determined coefficients.

- for the application of oscillations on radial direction, it has the expression:

$$K_{Prad} = \frac{K_{F_z}}{1+\frac{F_{yus}}{F_{zus}}-v_{med}} \cong \frac{K_{F_z}}{1+0.5v_{med}} = C_2 \frac{v_{med}^{\kappa_2}}{1+0.5v_{med}} \gamma_{med} = \frac{\kappa_2}{0.5(1-\kappa_2)}$$

(6)

where: C_2, k_2 are experimentally determined coefficients.

The results of theoretical and experimental researches developed so far in the field of metallic materials have revealed a significant decrease of the actually consumed average power during the processing, at the activation with ultrasound oscillations for high plasticity materials processing, with the small section of the chip, for the criterion of speed $v_{med} \geq 1$.

De-vulcanization of rubber waste in autoclave

Manufacturing the powder from tires with textile insertion was done using the following equipment: shredder, crushing roller (Kreeker), shredding mill, sieve for sorting, conveyor belts. The strips obtained by cutting tires in the shredder are shredding in the mill and then on the crushing roller, with the possibility of recirculating [11]. The resulted powder is taken from the conveyor belt and placed in rough mills, and from here is controlled pneumatically to the sieve for sorting and further to the autoclave to achieve de-vulcanization. Rubber de-vulcanization was done in an autoclave respecting the following parameters:

- temperature: 220-250 ^{0}C - depending on the type of rubber powder;
- pressure: 2.8-3.0 MPa - depending on the type of reclaimed rubber;
- de-vulcanization time: 115 min.

The very large share of refinery operations is because the mixing process of regenerated rubber takes place with difficulty due to moisture resulting from rubber resulting from the de - vulcanization. To reduce the weight of this operation it was intended to achieve a reduction in humidity and a reclaimed rubber as homogeneous as possible from the early stage of de-vulcanization in the autoclave. Rubber reducing humidity cannot be reduced thereby de-vulcanization using ultrasonic energy [12, 13].

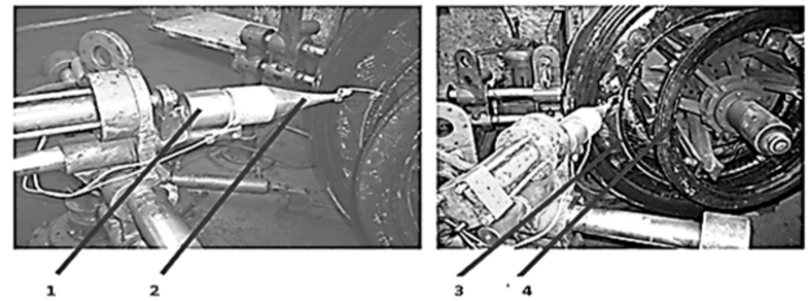

Fig.2. Overview on the technological plant used for ultrasonic activation tire shredding 1-ultraacoustic system, 2-tool used for shredding, 3-tire, 4-bead

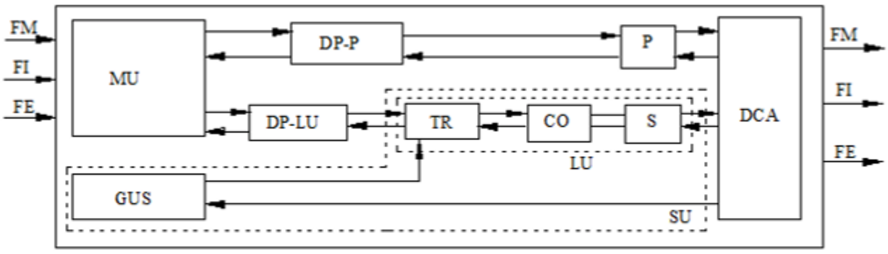

Fig.3. Structure of the ultrasonic activated shredding processing technological system: MU – tool-machine, DP-P – tire clamping device for shredding, P – tire to be processed, DP-LU – input device of the acoustic chain, TR – transducer, CO – concentrator, S – tool, LU – acoustic chain, SU – ultraacoustic system, GUS – ultrasounds generator, DCA – active control device, FM – material flows, FI – information flows, FE – energetic flows

To assess the quality of reclaimed rubber several quality indicators have been proposed over the years. About these indicators it can be said that some of them are antagonistic, others have become obsolete, etc. But it is always difficult to follow-up overall after several indicators simultaneously [14 - 16]. Therefore, in this paper we have proposed a general indicator of quality (GIQ) defined by the relation:

$$GIQ = \frac{100 - C}{100} \cdot M \cdot TS \cdot \frac{A}{100} \qquad (7)$$

where:

C is the percentage of ash, %;

M - Mooney viscosity;

TS - tensile strength, MPa;

A - elongation at break, %.

Results and discussions

The intensification of shredding of tires using ultrasonic energy

Based on the results achieved in the field of metallic material processing and especially of high plasticity materials, we considered that the use of ultrasonic energy in tire shredding may lead to special results. An adequate design of ultraacoustic systems, both for the experimental stand and for industrial use equipment, requires an analysis and a measurement of all their elements in order for the entire system to operate in resonance conditions. So, experiments used a specific ultraacoustic system consisting of a window type magnetorestrictive transducer and an exponential concentrator used together with the processing tool, (fig. 2).

The experimenting process followed the study of ultrasonic energy influence on the power necessary in the shredding process, as well as the evolution of the tool durability, respectively the possibility to increase work productivity in shredding off. In order to carry-out the experiments, various systems were designed necessary for measuring the shredding power, as well as for measuring the wear of the tool used for processing.

In order to measure the power consumed for shredding an ultrasound vibrations assisted processing technological system was created according to figure 3. As its subsystem, the ultraacoustic system consists of the GUS ultrasounds generator and the LU ultraacoustic chain. In turn, the LU ultraacoustic chain is a subsystem of the SU ultraacoustic system consisting of TR transducer, CO concentrator and S tool.

All these elements of the ultraacoustic chain are roughly fastened and have been designed and made in order to vibrate on the resonance frequency established. Except for the role played in the case of classical control processing of the piece and tool parameters at a given time, the DCA active control device has also the role of control of ultraacoustic system parameters and permanent re-adjustment on the resonance frequency in the case of ultrasonic vibrations activated processing. The ultrasound field processing plant used for tires shredding gave the possibility to measure and control the output signal in the ultrasounds generator, as a measure of the power consumed by the vibrating system.

Tires shredding is made using a tool-machine provided with an engine with a power of 11 kw and a speed of 1500 rot/min. Movement transmission from the engine to the backed off tire is made through a cinematic chain consisting in a speed reducer and a chain transmission and therefore the speed of the backed off tire is 31 rot/min.

In the case of classic shredding without the activation of the processed tool with the help of ultrasounds, the power necessary for shredding between 8-9 kw was measured, which proves the fact that this process is a high energy consumer. Taking this conclusion into consideration, the next stage passed to the activation of the tool used for shredding with a frequency of 15 kHz measuring again the power consumed in the cutting process and it was observed that the power consumed varied between 1-1.1 kw. This shredding power variation is mainly determined by the fact that in the used tire structure there are rubber areas with various characteristics and there are also cases in which the knife used for dividing may touch metallic or textile insertions that enter the structure of the tire.

Based on researches, it resulted that the use of ultrasound energy on tire shredding process causes a considerable decrease of the energy consumption, and this is 8-9 times higher than the case of classic shredding. Therefore, if we use ultrasound energy in the shredding process, the tool-machine used for shredding can be redesigned in the sense of providing this machine with a smaller energetic consumption electric engine and at the same time, the cinematic chain can be redesigned for transmitting the movement from the engine to the backed off piece in order to achieve an increase of the backed off tire speed. Also, the ultrasonic activated shredding process revealed a considerable decrease of the processing force considering the general relation $F_c = P/v$, and the force coefficient K_{Fi} as the ratio between the size of the shredding force without ultrasound activation F_i and the size of the force with ultrasound activation $F_{i\,US}$ (i = x, y, z) takes rather high values:

$$K_{Fi} = \frac{F_i}{F_{ius}} = 8 - 8.18 \quad (8)$$

Based on the results of this stage, we can draw the conclusion that the use of ultrasounds in tire shredding process causes the achievement of high economic effects due to the decrease of energetic consumption.

Because the speed of the backed off tire is rather low, this makes that productivity be inadequate. This low productivity of the first operations of superior recovery process of tires, namely shredding makes the entire process to be one economically unsuitable. In order for the capitalization process to develop with an adequate productivity it is necessary that the shredding operation develop by using more shredding machines, but this would result in a considerable increased of the energy consumed. Based on these reasons, this stage of researches followed to alter the cinematic chain of the shredding machine in order to replace the engine, the reducer and the chain transmission with a motoreducer coupled directly to the tire clamping device. The results from the previous stage when a high decrease of the shredding power and force could be noticed, allowed to make calculations in order to choose a motoreducer with a power of 1.5 kw and an output speed of 210 rot/min for the shredding machine.

Experiments have proved that the technological equipment can perform shredding for all backed off tires in very good conditions. In these conditions we get a decrease of energetic consumptions and a considerable increase of productivity. In order to analyze the influence of the ultrasound energy on productivity the productivity coefficient K_w was defined as the ratio between the speed of the ultrasound activation shredding n_{us} and the shredding speed without ultrasound activation n meaning:

$$Kw = \frac{n_{us}}{n} \quad (9)$$

Calculations have proved a value of the productivity coefficient of K_w=6.77. Therefore the use of ultrasonic energy in the shredding process may cause a constructive simplification of the shredding machine and also a considerable increase of the process productivity. Also, the use of ultrasonic energy in the shredding process causes a considerable increase of tire capitalization productivity allowing their higher capitalization with minimum costs.

In order to study the influence of ultrasonic energy on the tool wear, the same previously described processing parameters were used, and for measuring the tool wear, an active wear control system was used. Therefore, during the experiments, the tool wear was observed in the case of tires without ultrasonic energy and in the case of shredding with ultrasonic energy activated tools. The results achieved for the durability of tire shredding tools prove that tools durability increases 5÷7 times if they are ultrasound activated. In these circumstances, it is indicated that tires shredding be made with ultrasound activated tools in order to reduce the consumption of tools and to increase the process productivity.

The analysis of the current situation proved that tires shredding for their capitalization is a technological process accompanied by rather complex phenomena. Based on this conclusion, the paper aimed to find a technical solution that would allow to improve the performances of the shredding technological process and implicitly of the higher capitalization process of tires. Therefore, experimental researches were performed following a decrease of the energy consumed in shredding, and an increase of the shredding productivity and of tools durability.

Experimental researches proved the fact that the use of ultrasonic energy in the shredding process leads to very good results with special practical applicability. Therefore, the ultrasonic energy activation of the shredding tools leads to results that allow a considerable alteration of the cinematic structure of the shredding machine as well as a considerable increase of productivity. This makes the shredding process in the presence of ultrasonic energy improve considerably in relation to classic shredding without the use of ultrasonic energy. The main results give the possibility to integrate the shredding process in a high flexibility technological line that allows the capitalization of a large dimensional range of tires and tires made of various rubber mixtures with metallic or textile insertions.

The technical solution can be applied in practice with special results, being able to achieve an increase of tires superior capitalization possibilities and going further than the current 10 % threshold, and also a decrease of materials and energy consumptions and hence a considerable decrease of environmental pollution.

De-vulcanization of rubber by vacuum to the autoclave

Technological flow classically, currently used at de-vulcanization of rubber waste was improved by the introduction in the technological flow of auxiliary operation after de-vulcanization namely removing moisture from the autoclave by connecting the autoclave to the vacuum plant, (fig. 4).

By applying this new technology has succeeded in removing a quantity of 150 liters of waste water per 900 kg rubber once introduced in the autoclave. By applying the relation (7) there were calculated quality indicators for several types of obtained reclaimed rubber and there was noted with parameter 1 for reclaimed rubber obtained when was applied the autoclave vacuum and parameter 2 for reclaimed rubber obtained, (table 2).

Conclusions

Theoretical and experimental researches have allowed to find special technical solutions that allow to support the following conclusions:

-tires shredding operation is a complex operation that requires high energetic consumption and low productivity;

-researches aimed to identify the main parameters that characterize tires shredding operation and the process ultrasonic activation method;

-the ultraacoustic system that was designed and made allowed to active the shredding tool with a related ultrasonic energy and a frequency of 15 kHz;

-the shredding tool ultrasound activation resulted in a great decrease of the shredding force ($K_{Fi} = \frac{F_i}{F_{ius}} = 8 - 8.18$) and implicitly of the power consumed;

-reducing the power consumed in shredding causes the reduction of the energy consumed, but at the same time, this allowed to redesign the cinematic chain for the shredding machine drive, which resulted in a constructive simplification of the shredding machine and to a replacement of the high power electric engine used for driving with a smaller power engine;

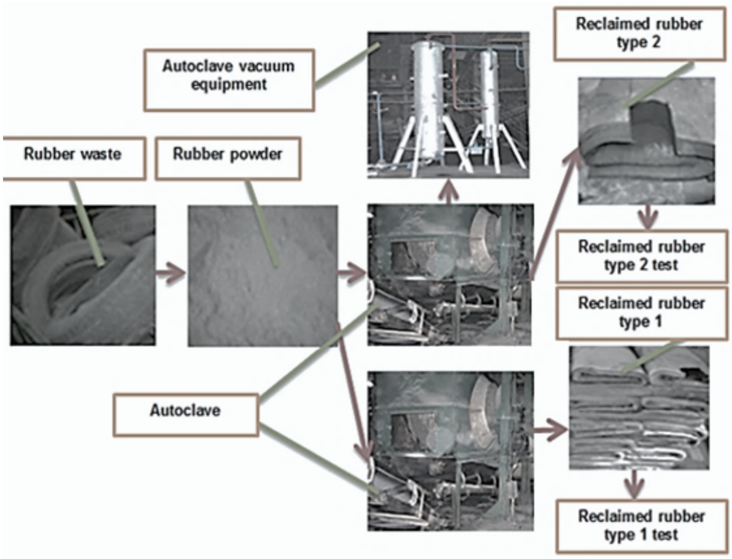

Fig.4. Synthetic image of the two technological flows

Table 2
GENERAL QUALITY INDICATORS OF RECLAIMED RUBBER TYPES OBTAINED

Reclaimed rubber type	Reclaimed rubber sub-type	General quality indicators, GIQ
A	A_1	323.2
	A_2	348.1
B	B_1	116.3
	B_2	146.7
C	C_1	344.8
	C_2	414.4
D	D_1	133.7
	D_2	171.2
E	E_1	129.4
	E_2	164.3
F	F_1	290.4
	F_2	338.8

-ultrasounds application during shredding allowed an increase of the process productivity $(Kw = \frac{n_{us}}{n} = 6.77)$ by altering the tire rotation speed;

-the use of ultrasonic energy in the shredding process makes this operation of waste tires capitalization technological process be adequate from technical point of view and have multiple possibilities of being integrated in a technological like for tire waste capitalization;

-researches results applicability in practice allows an increase of tires waste capitalization possibilities which allow a decrease of environmental pollution with such waste. These results can also be applied in the capitalization process of other plastic material wastes.

-the nature of rubber waste, subject to regeneration is essential to obtain enhancement of the regenerated rubber and future behavior of rubber products in exploitation;

-it was found in experiments that for example tensile strength and elongation at break are higher for certain types of regenerated rubber by 50 % compared with other types of reclaimed rubber;

-the characteristics of reclaimed rubber are improved substantially if following desulphurization a vacuum in the autoclave is applied and at the same time reduce the time and energy consumed in the process of regeneration;

-when the regeneration technology with vacuum of the autoclave is applied a simplification of the technological process is achieved by eliminating operations on foreign refining are shortened by about 30 %;

-the highest overall quality indicator is obtained if the reclaimed rubber is obtained from waste of technical plate and the conveyor belt with the application of improved technology for rubber regeneration.

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