Destruction of Polymers in Liquid Nitrogen by the Electrical Discharge

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Abstract – Technological processes of flexible polymer materials destruction are based on their transition to the brittle state after deep freezing, for example, in liquid nitrogen. In this case even insignificant physical loading can cause their destruction. Currently, cooled polymers are destructed in mechanical mills. This requires the construction of special devices where grinding media shall work perfectly in deep freezing conditions. The investigation of dielectric strength of liquid nitrogen and flexible polymers of different thickness put into liquid nitrogen proved the possibility of their destruction technology creation due to the electric breakdown and the creation of mechanical stress field from the expanding discharge channel. This can allow the destruction of both uniform and composite materials. Investigation results of breakdown voltage of liquid nitrogen and samples prepared from several types of rubber and other flexible polymer and biological materials cooled up to 77 °K are presented in the given paper. Energy characteristics of flexible materials mass disintegration reaching the powder state are considered.

Polymer wastes, including mechanical rubber products are accumulated in industrially developed countries. According to annual results the number of worn out auto-tires is more than 1.5 billion. Increase in the number of polymer wastes is constant, which creates ecological problems and leads to the loss of crude products that are to be included into the manufacture. Currently, not more than 20% of polymer wastes are being recycled.

The major problem concerning the utilization of polymer wastes is that the whole process is too expensive. This makes obtained crude products to exceed oil products in cost. Such balance of expenses does not stimulate recycling and explains why a number of states introduce special laws and programs thus creating favourable conditions for more effective recycling methods. It demonstrates the topicality of environmental issues, which are likely to become the main focus of the ecological policy in many countries of the world.

Today, one of the technological recycling lines of rubber technical products can be presented in the following way: assembling and classification of products; metal and other components separation; rubber disintegration to obtain required size of granulated materials, and its use as an additive compound to produce new rubber admixtures. Every mentioned procedure is very complicated and requires special elaborations. Let us consider the most expensive operations: separation of rubber from metal and obtaining of rubber granulated materials.

Mills, disk and rotary crushers where materials are affected by shear and crushing strength are used to obtain rubber crumb from high-elastic rubbers. In this case crude destruction is not efficient enough due to great energy losses in plastic deformation.

Table 1 shows disintegration energy parameters of the operating mechanical crushers. Thereby, destruction should be carried out in two stages: preliminary shredding using 3÷10 mm rotary impeller crusher and regrinding using disk mill [1].

Table 1. Disintegration energy parameters of the operating mechanical crushers

Rubber crumb size, mm	Productivity, kg/h	Energy consumption, kW · h/kg
+10–3	600	0.168
up to 1.5	350	0.288
up to 0.3	80	1.26

Energy consumption during auto-tires processing in high-elasticity state comprises 0.7÷0.8 kW · h/kg (disintegration up to 1 mm). Several devices are used in this technological chain. Increased energy consumption and poor reliability of system operating units are considered the major disadvantages of the described methods of rubber and rubber technical products processing.

Cryogenic methods, which imply cooling of raw materials up to the brittle temperature (~ 180 ÷ 220 °K) appear to be more promising. The transition of elastomers into the brittle state significantly decreases the loss of energy in the elastic deformation area. This improves energy and dimension parameters of disintegration and increases the possibility of other loading methods implementation, for example, by using the impact load, and others. At present, energy consumption ratio comes to ~ 0.2÷0.3 kW · h/kg during the disintegration of deep-cooled rubber up to 0.2÷0.3 mm (without taking into account energy consumption for liquid nitrogen manufacture ~ 1.2 kW · h/kg) [1, 3].

Thus, total energy consumption during cryogenic destruction using mechanical equipment and raw material breakage in high-elasticity state to obtain similar sizes is almost equal. In addition, deep-cooled polymer destruction has a number of advantages. Thermal destruction of polymers is eliminated due to environment inactivity, which allows to use secondary raw materials more efficiently, reduction range in one apparatus is increased, etc. However, the most urgent issue concerns the operating unit durability, especially in metal containing products disintegration.

High Voltage Research Institute of Tomsk Polytechnic University is developing deep-cooling metal-set rubber and rubber technical products utilization methods using electric pulse spark [2].

Electro pulse destruction method is based on the creation of the electric discharge channel inside the solid. When expanding this discharge channel generates shock waves and creates dynamic stress field (mainly of shifting or expanding nature) inside the solid. Electric spark usage as an operating unit excludes the problem with operating unit durability, and pulse impact loading with amplitude of up to 10^9 Pa allows analyzing deep-cooling polymers efficient destruction.

The given research deals with the conditions and parameters of high voltage impulses whereby discharge channel is formed in the thickness of various rubbers placed in the liquid nitrogen. The estimation of the destruction index of metal-set rubber and rubber technical products under their mass disintegration is also conducted.

Investigations were carried out using pulse voltage generators that provide the modification of pulse amplitude from 160 to 300 kV, pulse energy in the range of 300÷800 J, and discharge circuit inductivity from 15 to 100 μH. Destruction process was conducted in special cryogenic operating chambers supplied with one high-voltage electrode. Grounded electrode represented metal hemisphere with special holes for final product classification [3].

Rubber samples filled with technical carbon and kaolin (caoutchouc content 40–50%) and rubber samples filled with chalk and talc (caoutchouc content 33–35%), and specially designed model rubber samples with metal insertion were investigated. Rubbers filled with technical carbon and kaolin (ШБТМ-40, ШВП-50) are used in the cable industry as a cable containment shell, rubbers filled with chalk and talc (ТСШ-33, ТСШМ-35) as cable insulation. The choice of these rubbers is caused by the variety of physical, mechanical, and electrophysical properties of rubbers applied in today's industry. Investigations of mass destruction phenomenon were conducted on the given rubber types, conveyer belt reinforced with metal, auto-tires sections, etc.

To form discharge channel inside the material there is a need for such a pulse form and its amplitude as those implying that the electric strength of the environment (for example, liquid nitrogen) is higher than that of the destructible material.

Figure 1 shows volt-second characteristics of deep-cooled rubbers together with volt-second characteristics of liquid nitrogen. It is obvious that there is a need to consider a voltage stress $E = 9.5 \div 13$ kV/mm for rubbers filled with technical carbon and $E = 11 \div 15$ kV/mm for rubbers filled with inert material (chalk, talc) when choosing the voltage level of the high-voltage impulse. It is necessary to use impulses with the voltage rate of rise not less than 400 kV/μs for rubbers filled with technical carbon and not less than 1000 kV/ μs for rubbers filled with inert materials to implement the electro pulse method.

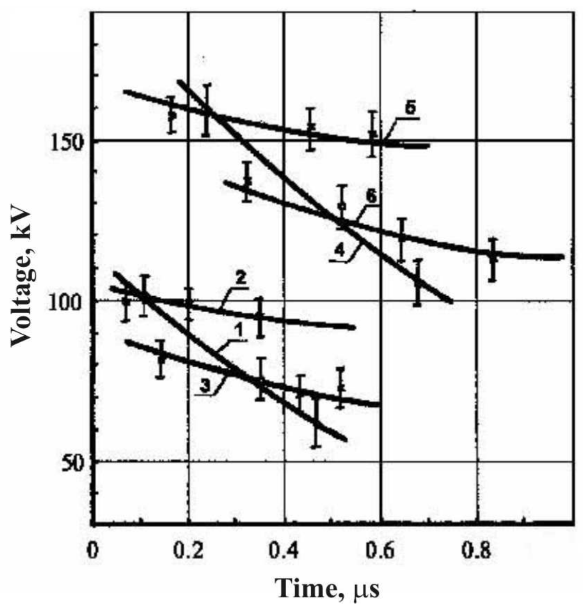

Fig. 1. Volt-second characteristics of deep-cooled rubbers (*2*, *5* – rubbers filled with chalk and talc; *3*, *6* – rubbers filled with technical carbon and kaolin) together with volt-second characteristics of liquid nitrogen (*1*, *4*). *1*, *2*, *3* – sample thickness $d = 8$ mm, *4*, *5*, *6* – sample thickness $d = 16$ mm

Using obtained data, a number of operations were carried out to investigate energy and dimensional characteristics of mass electro pulse disintegration of deep-cooled rubbers and rubber technical products.

During the analysis of rubber disintegration characteristics it was determined that it is advisable to start the destruction process in the material cooled up to the embrittlement temperature (the temperature in the centre of a sample should be not less than 150 °K). This requires some certain amount of time to cool, which depends on the thickness of samples. There is the best energy value of a unit impulse (W_0) for every rubber type and disintegration size whereby the destruction of material is more efficient [3].

Table 2 shows best values of parameters: pulse energy (W_0) and interelectrode distance (d_{opt}) necessary for more efficient breakage of deep-cooled rubbers, and relative productivity and energy consumption values obtained using these parameters.

As seen from the obtained results, energy consumption of the electro pulse destruction process taking into account production expenses of liquid nitrogen is a bit lower (~10%) than that obtained using mechanical equipment. However, the given advantage is not so significant to be implemented.

The destruction of metal-set rubber technical products, the disintegration of which is almost impossible in mechanical apparatus is considered to be more perspective in electro pulse technology implementation.

Table 2. Rubber mass disintegration parameters

Material type	Initial product size, mm	Final product size, mm	Pulse energy W_{opt}, J	Inter-electrode distance D_{opt}, mm	Specific productivity, g/pulses	Productivity, kg/h	Energy consumption*, kW · h/ kg
Rubbers filled with technical carbon and kaolin	30÷50	–5	450	21	1.33	38.8	0.085
	30÷50	–2	550	22	1.01	28.8	0.1
	30÷50	–1	630	23	0.63	18.1	0.16
Rubbers filled with chalk and talc	30÷50	–5	580	22	1.15	33.12	0.102
	30÷50	–1	700	22	0.47	13.5	0.275

* Without taking into account expenses for liquid nitrogen production (1.2 kW · h/kg).

Conveyor belt segments of size 140×140×40 mm^3 having 3 metal figurate boards 4 mm thick, not connected with each other and placed inside rubber cover were used in the investigation of such materials disintegration. Segment weight was 0.5 kg. Segments were placed transversely to the high-voltage electrode and moved as rubber was separated from the metal surface. Table 3 shows results corresponding to 100% separation of rubber from metal, while Fig. 2 reveals the external physical configuration of samples and obtained products.

Table 3. Results of conveyor belt fragmentation

Pulse energy W_0, J	Number of pulses per one segment	Specific productivity (frequency 3 pulses/sec), t/h	Energy consumption*, kW · h/t
500	35	0.15	9.86
600	25	0.21	9.24
780	10	0.54	4.37
1560	8	0.67	7.00

* Without taking into account expenses for liquid nitrogen production.

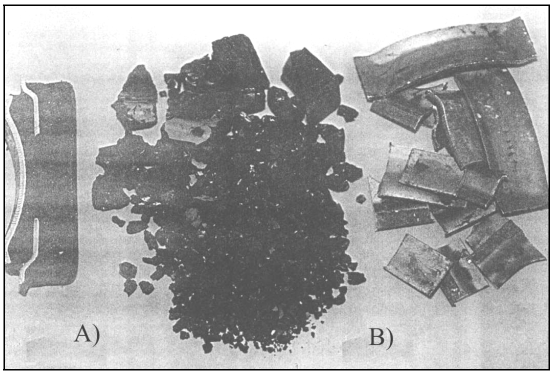

Fig. 2. Conveyor belt segments before (*A*) and after (*B*) fragmentation

Separated metal elements have their initial form after processing and can be used for the second time. Obtained results show that the use of electro pulse method for the utilization of such materials is very effective, i.e. at energy consumption ~ 4.3 kW · h/t there is a possibility to achieve productivity equal to ~ 0.5 t/h per one high-voltage electrode with cycling frequency equal to 3 pulses/s. Reduction of the liquid nitrogen consumption is the major technological task. This can be achieved by energy regeneration, special operating apparatus construction and other developments of domestic and foreign companies.

The destruction of metal- and textile-set rubber technical products, among which are auto-tires, pressure hoses, elastic clutches, and others, are of particular interest. Experiments were conducted in auto-tires segments using conveyor belt element processing scheme. Pulse energy comprised 780 J; tire segment was placed so that the major rubber layer ~ 30 mm thick was under the high-voltage electrode. The basic rubber part separated penetrating the metal cord unit after 10 pulses supply. After 20 pulses supply the metal cord separated from the segment and partially destroyed thin inner layer of rubber. However, textile undercoat remained undamaged due to unchanged physical and mechanical properties of textile under liquid nitrogen temperatures. Investigation results show that metal- textile-set rubber technical product utilization should be carried out in several stages; using electro pulse method to separate rubber bulk from the metal component, and textile component processing can be performed using traditional methods.

Thus, the conclusions are as follows:

– the electro pulse method of deep-cooling rubbers disintegration to various dispersion levels can successfully compete with present mechanical and cryogenic methods;

– the most efficient area of the electro pulse method usage is its implementation in combined metal-set rubber technical product utilization, where it has significant advantages: low energy intensity, minor deterioration of the operating units, high separation level of rubber and metal;

– it is advisable to utilize products having a textile constituent in several stages using the electro pulse method for the initial destruction of the major rubber level.

References

[1] V.F. Drozdovsky, Caoutchouc and rubber **4**, 23 (1992).

[2] B.V. Semkin, V.I. Kurets, A.F. Usov, *Basics of electro pulse decay of materials,* St. Petersburg: Science, 1995, pp. 46–73.

[3] V.I. Kuretz, M.A. Soloviev, G.P. Filatov, T.I. Alekseeva, Caoutchouc and rubber **6**, 26 (1999)