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IMPORTANCE OF COMMINUTION IN PLASTICS PROCESSING

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Abstract

The state-of-the-art concerning size reduction of polymer materials has been presented in this paper. The main objectives of this operation as well as the ways of their realization have been discussed. The variants of matching action of cutting edges when comminuting polymers have been gathered in tables. The universal stand for carrying tests of energetic verification for the new rotational size reduction techniques as well as preliminary results have been shown. It has been stated that geometry of matching cutting edges has considerable influence on energy consumption. The directions of further investigation have been pointed out.

Keywords: *polymeric materials, disintegration of polymer, cutting forces, test stand*

1. Introduction

In 2005, global production of plastics exceeded the magical limit of 200 million tonnes [1] which means that the total resource mass of secondary materials (commonly referred to as waste) has also proportionately increased. Many research centres in the world undertake research and development as well as implementation work which is aimed at proper use and management of secondary resources (including cross-linked polymers and elastomers), through material, raw material recycling [2]. High requirements of development and improvement of composite components preparation techniques for further processing by extrusion, injection or molding method are often demanded for material recycling and composite materials technology.

Comminution occurs very often, apart from separation, washing, or decomposition, as one of the preparatory processes (components) in the formation of composite materials which means that it is a very important and still valid problem to be solved from the technological, structural, economic and environmental protection point of view. Comminution – scientifically attributed by R. Sikora [3] to the discipline of machining of plastics.

Preparation of composite material components by comminution is usually conditioned by: the expected degree of comminution, appropriate granular distribution, desired morphology of elementary particle and others [2-6]. The mechanical comminution performed by the rotating knife cutting [6], to be discussed in detail in point 2.2 of the study may meet the mentioned requirements for polymeric materials and cross-linked elastomers.

2. Comminution implementation

2.1 Phenomenological models

The basic comminution methods use three main types of loads: compression, tension and shearing. Depending on the physical, strength-related properties and type of comminuted material, a proper shape and particle size-reduction should be applied in the construction design to achieve high efficiency of the process, which can be achieved through:

a) crushing obtained by squeezing aparticle using two surfaces rotating with equal speed (Fig.1-1),
b) breaking by impacts, induced by high-speed machinery elements acting on the particles (Fig. 1-2),
c) rotary cutting performed by knives' cutting edges (Fig.1-3),
d) quasi-shearing as an eco-friendly method of material comminution (Fig. 1-4),
e) mulling by rubbing two surfaces, one of which is stationary (Fig. 1, 5, 6).

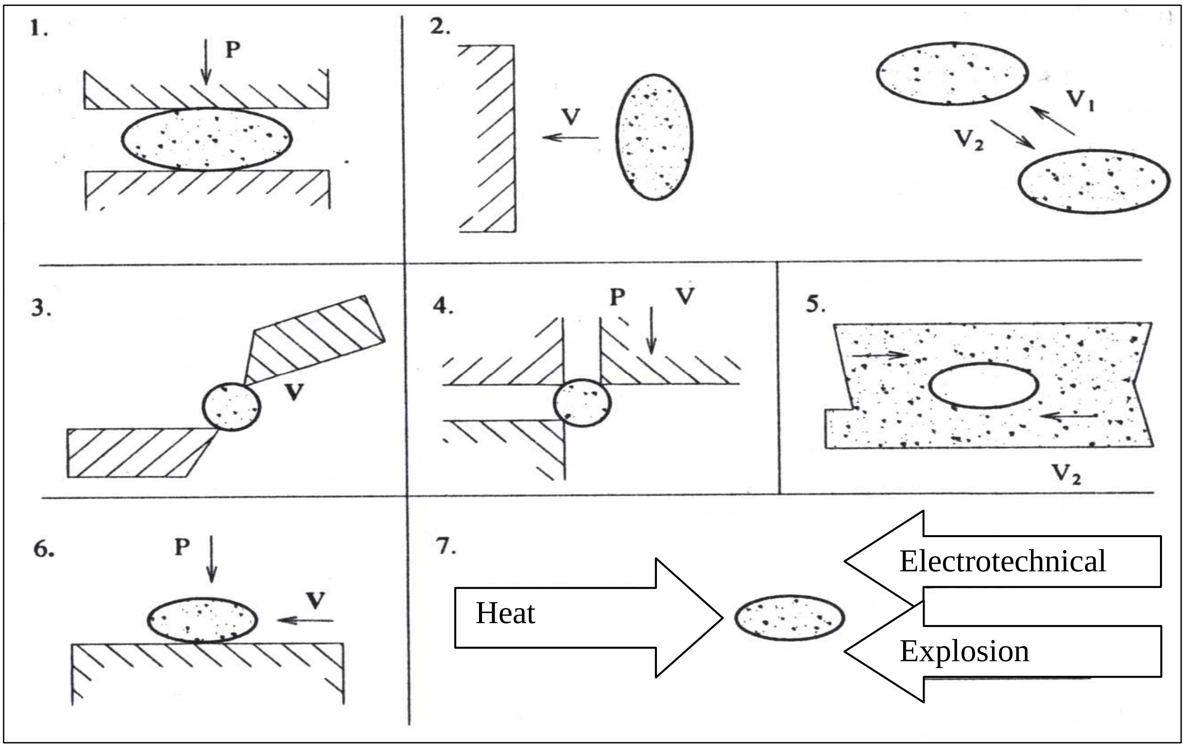


Fig. 1. Phenomenological models of size-reduction [4,5,7]

For thermoplastics (also for elastomers), the dominant role does comminution by knife cutting (Fig. 1-3), also known as rotary. Noteworthy is also polymer comminution through the so-called quasi-shearing (phenomenological model marked as fig. 1-4) which is characterized, among others, by low energy consumption, low noise and excellent repeatability of granular classes. This method of comminution is described in greater detail in the work of J. Flizikowski in [4].

2.2 Rotary knife cutting

The comminution method of rotary cutting is carried out in knife mills. A schematic diagram of a typical device for comminution of polymeric materials is shown in Figure 2. Rotary cutting of plastics and secondary elastomers (commonly known as waste) is a result of the collaborative work of a rotating knife executing a rotary movement (centrifugal) and a stationary knife embedded in the comminution device housing. An effective division of the comminuted material (secondary rubber) occurs only if, moved around in the pulveriser chamber, it finds its way into the clearance between the cutting edges of the knives : stationary and rotary.

Rotary knife cutting, which is shown in general in fig. 3, is a result of the collaborative work of a movable knife, rotating knife and stationary knife embedded in the comminuting machine housing. During rotary cutting, the polymer lies on the stationary knife rake face surface from which a piece of element (particle, grain) is cut off (separated).

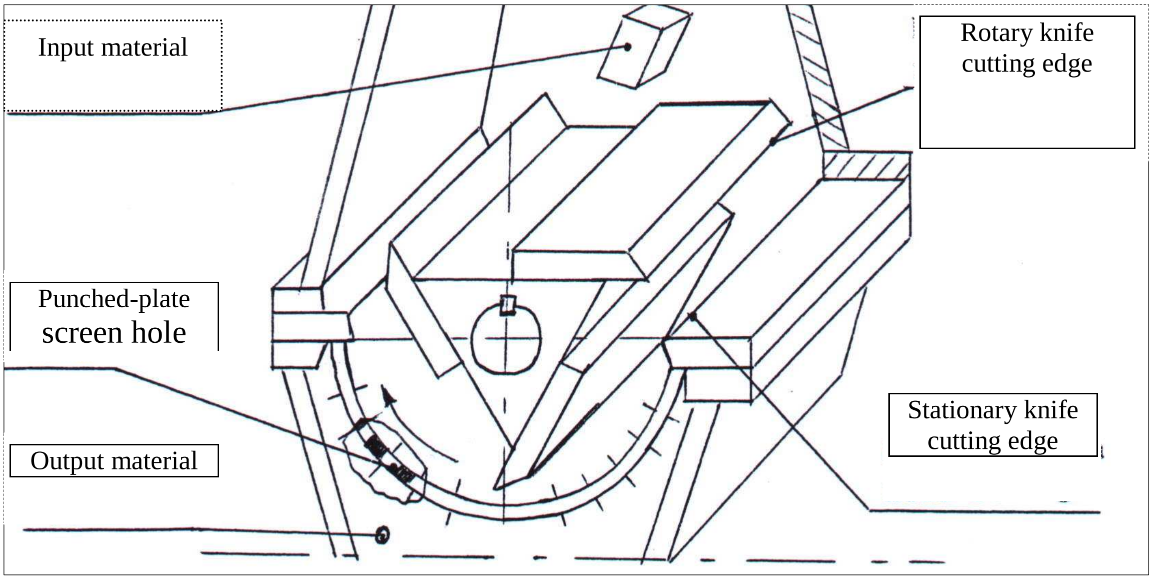


Fig.2. The view of typical device for size reduction of plastics and elastomers [5,6].

The force components of, which are the result of the cutting force $F_{c,}$ affect the part separated. These are as follows:

- the F_p material particle acceleration force (depending on cutting speed),
- the F_d material particle deformation force (depending mainly on the rotary knife value),
- the F_r force of friction of rubber against the rake face surface of the rotary knife (depending mainly on the stiffness of the material cut and the values of the friction coefficients) the F_v force of rubber separation (depending mainly on the resistance value).

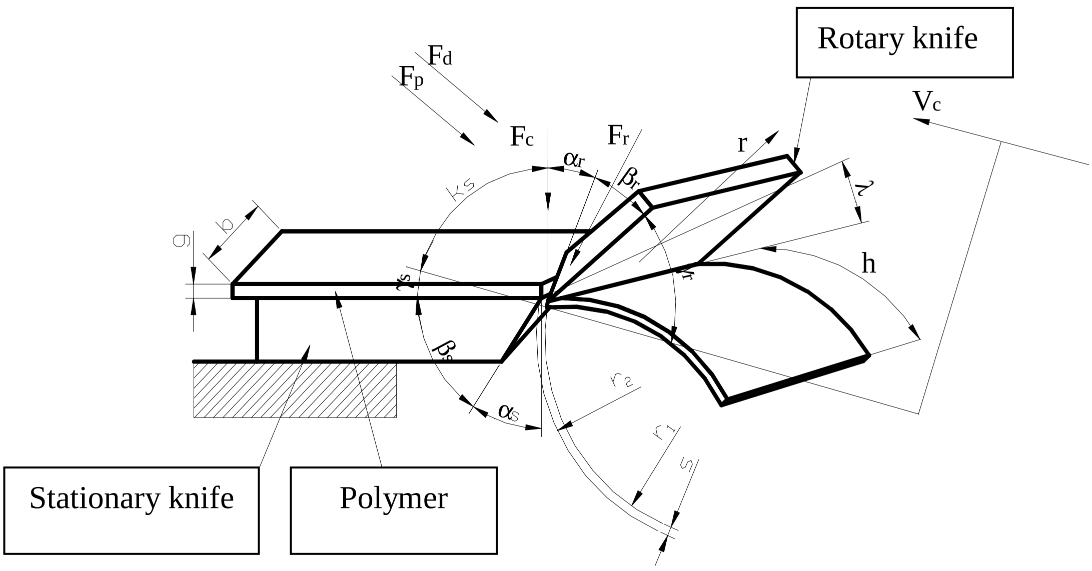


Fig.3. Scheme of the geometry of the rotating knife size-reduction method [6].

Given the above preliminary analysis, it can be assumed that the resultant cutting force will depend on: the cutting speed, the dimensions of the elements comminuted (feed size) and material stiffness, the coefficient of friction between material and steel, the cutting resistance, geometry of stationary and rotary knife blades (especially the blade angles) and the inclination angle of the main cutting edge of the stationary and rotary knives in relation to the pulveriser rotor axis. It can therefore be assumed that the overall semantic model of the resultant cutting force value - unknown as to the precise direction – during rotary cutting is presented by the following formula [4-6]:

$$F_c = f(b, g, h, \alpha_r, \beta_r, \gamma_r, \alpha_s, \beta_s, \gamma_s, \lambda, v_c, ...)$$

where:

b, g - the width and thickness of materials,

h - the length of the material element being cut,

α_r and α_s – application angles of the knife: rotating and stationary (stationary and rotating knife geometry)

β_r and β_s- knife blade angles: rotary and stationary,

γ_r and γ_s - knife rake angles: rotary and stationary,

λ - the inclination angle of the stationary and rotating knife main cutting edge in relation to the rotor axis,

vc – cutting tangential velocity

s – clearance between the knife cutting edges: stationary and rotary,

σ_c - cutting resistance and others.

Most of the basic parameters of the knife geometry during comminution (for example α_r and α_s,, β_r and β_s, γ_r and γ_s, λ) are relatively well known and have been described in the literature [4-9]. Investigation of other parameters requires research and development work

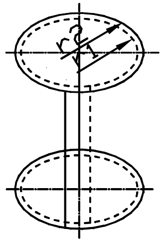
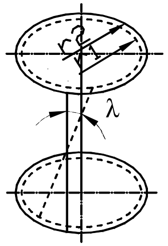
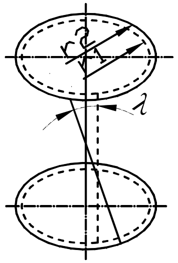
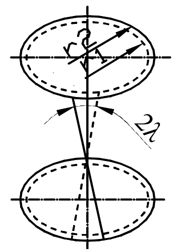
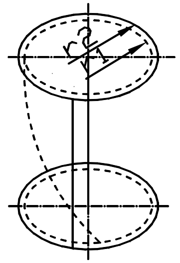
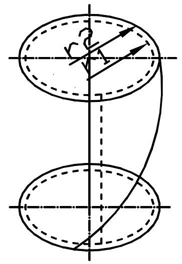
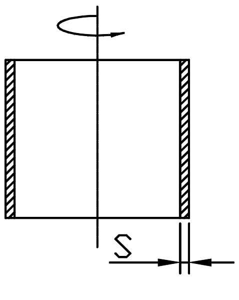
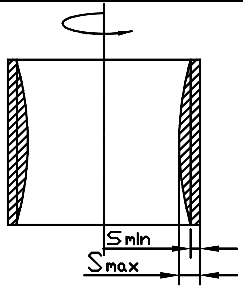
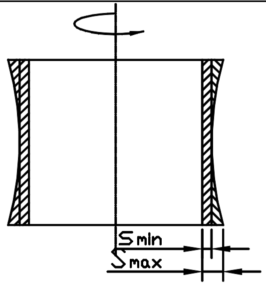
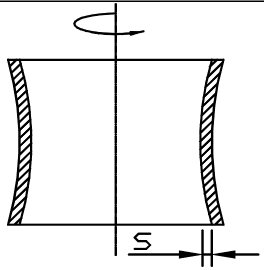
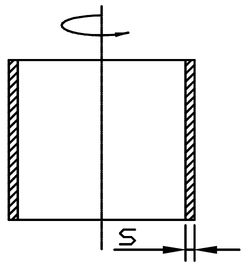
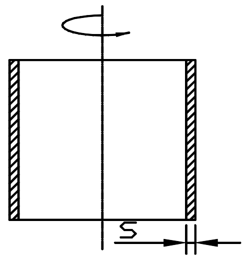
2.3 Cooperation variants of knife cutting edges

Rotary and stationary cutting edges of the knife can work together in a varied mutual arrangement. Table 1 summarizes variants of the knife cutting edge co-operation known from literature and own studies, providing the respective cutting edge co-operation scheme, the levelling of the surfaces developing through the cutting edges spinning around their axis, the shape of the clearance between the blades [6,9,11,12]. As is clear from the analysis of literature, comminution equipment design solutions often use a cutting edge cooperation case as indicated in Table 1 as B or C, with regard to the issue of reducing comminution energy consumption and noise level compared to cooperation, marked A. In recent years, the type of cooperation recommended (indicated in Table 1 as D) is referred to as "hyperboloidal"- as described by R. Konieczko [6.10] and is also referred to by H. Bauer [9] as "double-diagonal" for which energy consumption and noise levels are much lower compared to B and C cooperation.

As follows from preliminary tests conducted and results obtained, by applying an appropriate cutting edge cooperation design solution conventionally referred to as “quasi-tangent” [11,12], it is possible to reduce comminution energy consumption compared to D cooperation. These observations, preliminary results and own deliberations qualify the author to formulate the following hypothesis:

It can be assumed that there are rotary and stationary cutting edge cooperation conditions under which the energy consumption of the comminution process (or cutting force) will be smaller than for variants known and used in practice so far.

Table 1. Variants of matching edges of cutting knives [6,11,12]

	Rotary and stationary cutting edges of the knife in parallel to rotation axis. $\lambda = 0^o$	Rotary cutting edge of the knife at the angle of λ, stationary cutting edge of the knife in parallel to rotation axis	Rotary cutting edge of the knife in parallel, stationary cutting edge of the knife at the angle of λ to rotation axis	Rotary and stationary cutting edges of the knife inclined in the opposite direction at the angle of 2λ	Helical shaped cutting edge of rotary knife, stationary cutting edges in parallel to rotation axis*	Helical shaped cutting edge of stationary knife, rotary cutting edge in parallel to rotation axis*
	A	**B**	**C**	**D**	**E**	**F**
Scheme of cutting edges mate						
Surface equations created by rotation of knifes' cutting edges	Rotary cutting edge $x^2 + y^2 = r_1$ Stationary cutting edge $x^2 + y^2 = r_2^2$	Rotary cutting edge $\frac{x^2 - y^2}{a^2} - \frac{z^2}{c^2} = 1$ Stationary cutting edge $x^2 + y^2 = r_2^2$	Rotary cutting edge $x^2 + y^2 = r_1^2$ Stationary cutting edge $\frac{x^2 - y^2}{(a+s)^2} - \frac{z^2}{c^2} = 1$	Rotary cutting edge $\frac{x^2 - y^2}{a^2} - \frac{z^2}{c^2} = 1$ Stationary cutting edge $\frac{x^2 - y^2}{(a+s)^2} - \frac{z^2}{c^2} = 1$	Rotary cutting edge $y = x \cdot tg \frac{z}{k}$ Stationary cutting edge $x^2 + y^2 = r_2^2$	Rotary cutting edge $x^2 + y^2 = r_1^2$ Stationary cutting edge $y = (x+s) \cdot tg \frac{z}{k}$
Clearance shape between cutting edges						

3. Research purpose and methodology

This study aims to compare the energy consumption of the rotary knife cutting process (by defining the resultant cutting force) for selected types of cutting edge cooperation identified in Table 1 as C, D and E. Two types of materials were used for the studies: polystyrene (PS) and soft polyvinyl chloride (PVC) in the form of plates with a thickness of g_1 = 1.2; g_2 = 2.4 and g_3=3.6mm.. The clearances between the cutting edges were as follows. S_1 = 0.1 and S_2 = 0.2 mm. In order to compare the energy consumption for the types of cutting edge cooperation referred to, research was conducted in two stages. During exploratory research, not recounted in this paper, optimum values of angles λ and 2λ were first determined (for C and D according to Table 1), for which the cutting force value was the lowest. The optimal values of λ and 2λ determined were then used for the main research –comparative.

4. Research station

To achieve the assumed research goal and verify the hypothesis formulated, a universal comminution research station was developed whose versatility means that it can implement all types of knife cutting edge co-operation given in Table 1. In addition, a relatively wide range of clearances between the cutting edges can be used, the values of which are recommended in production facilities. A schematic diagram and major operating elements of the comminution device are shown in Figure 4.

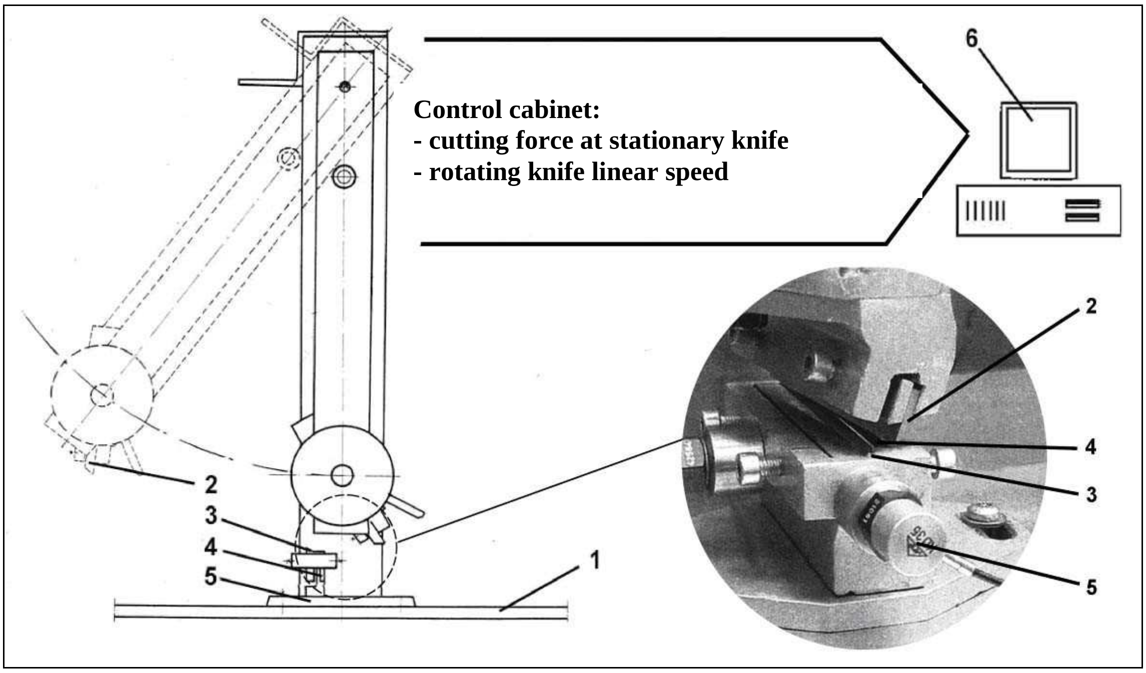


Fig. 4. Scheme of test stand for size reduction of polymers: 1-base, 2-rotating knifes, 3-stationary knife, 4-material to be size reduced, 5-piezoceramic sensors, 6-control cabinet

An important feature of the research station is that for all comminution variants, it makes it possible to record the cutting force components in the direction of the *x* and *y* axis and, if required, also in the direction of the *z* axis [11,12]. The research station shown in Figure 4.,uses piezoceramic transducers that work with a type SVAN vibration analyzer with a four-channel SV06A preamp (Brühl and Kjaer) [12].

5. Test results

The test results of the impact of the type, thickness of the polymer material and the clearance between the knives for the cutting edge co-operation types adopted, i.e. A, C and E on the cutting force are shown in Figure 5 and 6. When analyzing the results obtained, note that in the area surveyed, the cutting force for PS and PVC is the lowest for variant E. This results from the fact that the cutting

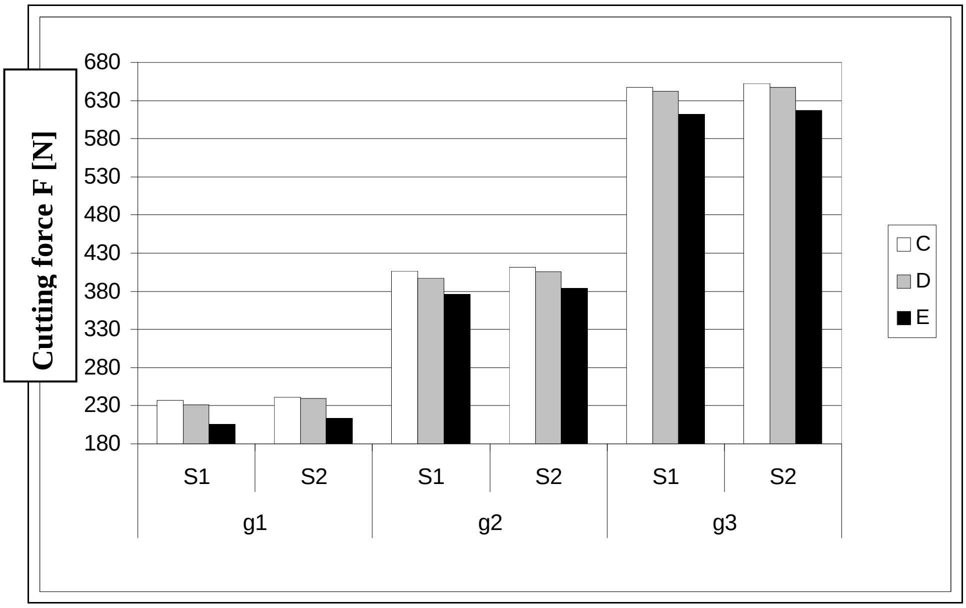


Fig. 5. Relationship between cutting force F and knife cutting edge cooperation type, value of clearance between knives S, thickness of material g (for PS)

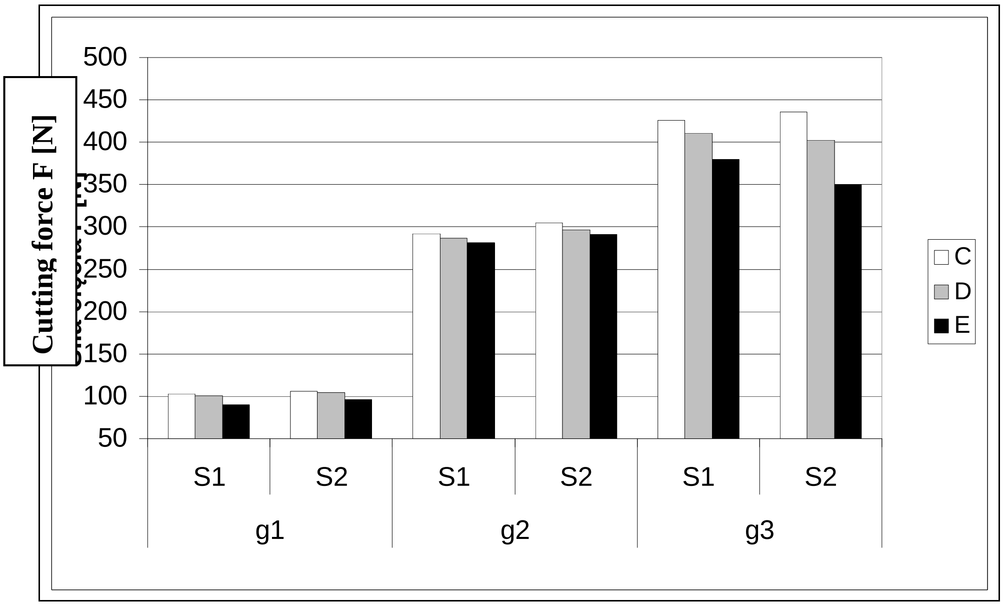


Fig. 6. Relationship between cutting force F and knife cutting edge cooperation type, value of clearance between knives S, thickness of material g (for PVC)

force is perpendicular to the material comminuted which is, among others, the essence of the patent obtained by the author [11]. Unlike in the case of C and D, no pushing of material along the cutting edge occurs here, which, as mentioned by R. Konieczka [6.11], is a result of a tangential component, whose share in the total (resultant) cutting force, as established by W. Bauer, is quite significant, and highly depends on angle 2λ [9].

6. Conclusion

As follows from the preliminary research results obtained, a cutting force reduction was achieved for the polymer materials investigated, i.e. PS and PVC by about 20%. The results of own laboratory tests and literature reports indicate that there are reserves for a reduction in the cutting force required to separate the polymer material, which is directly related to the reduction in energy consumption of the comminution process while maintaining high quality of the comminution product. The knife-based comminution design solutions used to date do not use all the knife cutting edge cooperations possible to be implemented. The results obtained at the model research stations should be a basis for the implementation of science and technology development using a knife pulveriser with a suitable design. Further work in this area is recommended, given the high energy consumption of comminution.

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