Multiple-Disc Milling Assembly For Polymers Recycling

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Abstract
Development of recycling science causes facilitates in range activity project-design of machines. This paper presents an example of grinder design analysis and loads in a milling assembly. The analysis of multi-disc grinder is performed by means of advanced software such as TEST-4-TPTS and PSI-GAD-III. In experimental research, the a program of quasi-shearing[1] of plastics pipe specimens performed primary and recycled polymer in order to determine strains and loads in actual grinder.

الخلاصة
لتطوير علم التدوير (تدوير البوليمرات) يتطلب وسائل ونشاط في مجال المشاريع والتصاميم للمكائن. هذا البحث يعرض مثال لتحليل تصاميم مكائن القص (التقطيع) والأحمال المؤثره عليها عند وحدة القص (التقطيع) ومبينه بواسطة استخدام برامج الكمبيوترالمتقدمه مثل:

PSI-GAD-III و TEST-4-TPTS

بحث للتجارب جرت (عملت) ببرنامج القص (التقطيع) للأنابيب البلاستيكيه (البوليمريه) الأوليه وفي التدوير لمقارنة نتيجة تجارب الأحمال و الأنفعالات في هذه المكائن.

Key words: disc grinders, polymers recycling, computer-aided design CAD, quasi-shearing, milling,

1. Introduction
Modern tools of computer-aided recycling machine design, such as ECODESIGN, to help design engineers to develop new concepts and solutions(Drzymala, 1992; Flizikowski, 1994; Flizikowski, 1996; Flizikowski, 1998; Flizikowski & Macko, 2001; Macko, 2000). These also facilitate implementation of the new ideas into technological and production application. On the other side, in an include design-implementation process one can easily employ theoretical data and experimental results in modernisation of construction and operation principle of machinery.

However, the existing state of knowledge is still unsatisfactory, as far as fundamental loads and material machining mechanisms are concerned. There are a lots of data available that concern grinding of minerals, but these are hardly applicable to describe machining and formation mechanisms of polymers, because characteristics of polymers and minerals are inhomogeneous. In some of the works, the attempt is made to use the methods of fracture mechanics of brittle materials, such as ceramics, but these attempts are not quite successful. Some other works describe relations between shear angle and shear stress during cutting (Macko, 2000). One generally agrees, however, that there is no universal milling description method today that would be useful for a wide spectrum of materials.

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[1] quasi-shearing – this shearing is the same and near technological shearing such as riveted-joint

2. Mill Enginering For Polymers Recycling

A method of modelling of grinder constructions, applicable to plastics recycling processes is proposed in this paper. The method represents a unified approach that integrates the essential features of previously developed analytical and numerical models. A systematic approach, employed in the method, facilitates recognition of important features and characteristic phenomena associated with multi-disc milling, and allows one to incorporate them into the model creation process (Flizikowski, 21998). For example, one can derive the relationship between dimensions of particles before and after shredding, speed of the milling process, etc.

2.1. Structural description of multi-disc milling assembly for polymers recycling

The fundamental feature construction of the multi-disc cutting mill designed for pieces materials is that the device consists of a set of working discs mounted co-axially on a shaft. Holes in the discs have cutting edges where shape depends on the kind of material (fig.1).

Fig.1.

Multi-disc cutting mills belong to the group of devices in which the process of comminution is performed at linear speed of the cutting edge of approximately 1 m/s, and the noise level is low to 76dB. The comminuted material remains in a permanent contact with the cutting elements within the comminution area. This property, and the lowered linear velocity, are two basic factors that contribute to high efficiency of the process (fig.1) (Drzymala, 1992; Flizikowski, 1996).

2.2. Process description of plastic pipe quasi-shearing

It is assumed that the pieces material is subjected to quasi-shearing (fig.1 a, b, c) that results in shredding of the material. Loads, stress and strain in material grains may appear on one or two edges of holes in the discs that are in rotational motion with respect to one another (model according to fig.1).

The shredding process takes place when disc 2 (fig.1 b) moves with speed v_1 with respect to disc 3, while the latter moves with speed v_2. The comminuted material 1, which is forced through holes of diameter d_1 and d_2, is plastically strained by the edges of two holes in adjacent discs. The shredding velocity is equal to the difference of linear velocity of the hole edges. In experiments described in the paper, the shredding process was performed by means of a cutting mill, consisting of a set of discs, having the form of the working assembly shown in fig.1.

Fig.2.

The calculation of the function object of testing and multiple regression $P = f(\Delta l)$ – (P-force of quasi-shearing, Δl-slat dislocation, blade angle $\beta < 60^o – 120^o >$) as the equations of 4-th degree made by using software Excel and Cadex: Esdet (equations: (1)-(5)). These results, decrease coefficients of process PE-LD-pipe milling (Flizikowski & Macko, 2001; Flizikowski & Macko, 2001):

$$\beta = 60^o:$$

$$P = -5E\text{-}05\Delta l^4 + 0{,}0058\Delta l^3 - 0{,}2548\Delta l^2 + 4{,}8103\Delta l - 26{,}105 \quad (1)$$

$$R^2 = 0{,}8824$$

$$\beta = 75^o:$$

$$P = -3E\text{-}05\ \Delta l^4 + 0{,}0036\ \Delta l^3 - 0{,}173\ \Delta l^2 + 3{,}6626\Delta l - 20{,}887 \quad (2)$$

$$R^2 = 0{,}9006$$

$$\beta = 90^o:$$

$$P = -2E\text{-}05\ \Delta l^4 + 0{,}0033\ \Delta l^3 - 0{,}1687\ \Delta l^2 + 3{,}8256\Delta l - 22{,}465 \quad (3)$$

$$R^2 = 0{,}912$$

$\beta = 105^o$:

$$P = -2E\text{-}05\ \Delta l^4 + 0{,}0023\ \Delta l^3 - 0{,}1272\ \Delta l^2 + 3{,}1637\Delta l - 20{,}444 \quad (4)$$

$R^2 = 0{,}9071$

$\beta = 120^o$:

$$P = -2E\text{-}05\ \Delta l^4 + 0{,}0026\ \Delta l^3 - 0{,}1428\ \Delta l^2 + 3{,}4036\Delta l - 21{,}893 \quad (5)$$

$R^2 = 0{,}9069$

Collection of special plastic properties to delimitations of technological parameters quasi-shearing, and then of characterizations constructed shredder (tab.1 and tab.3) (Drzymala, 1992; Flizikowski, 1996; Flizikowski, 1998).

Table. 1.

Table. 2.

Table. 3.

2.3Analysis of process solutions and the obtained results

The pieces of the material were fed through the hole in the top fixed plate. After shredding, the product was released through the slot between the discs or it passed through the pack of discs with holes, for instance moving vertically down. Before design requirements for the multi-disc cutting mill are analysed, one should define the area of acceptable solutions (fig. 3) that meet the assumed usability criteria ($X \in \Phi$).

Fig. 3.

Operational characteristics of elements, proposed for the model and for the actual device, C_{ks}:

– characteristics of motion, including (according to fig.1):

- linear velocity of holes in discs, v_i, $v_r = f(\omega_i)$,
- difference between angular velocities of discs,) $\Delta\omega_i$;

Execution of the process must guarantee an appropriate evolution of kinematics, dynamic and efficiency parameters (fig.2):

- irregularity kinematics, Δk, irregularity dynamic, Δd, efficiency, $\Delta\eta$.

An adequate efficiency η must also be ensured.

Important factors in the power feed of the shredder are the states of kinematic transmission *iki,* and dynamic transmission *idi.* The following three kinds of cutting assembly velocity control can be applied:

- step less, type bsc, stepped, type bss, mixed, bsm, with step less drive of the first disc, and stepped for the remaining ones.

Depending on the construction of the cutting mill, the mass of comminuted material can pass through the cutting assembly in the following ways:

- through the clearings between discs, type S1,
- across – through the holes in assembly discs, type S2,
- partly through the clearings, and partly through the holes, type S1/2.

The multiple disc shredder is researches object, the discs have holes of grinding edges arranged on diameters, which increase from the inlet to outlet, and the velocity between adjacent discs is a grinding plastic pipe velocity (fig.1. fig.2).

3. Conclusion

In the paper area of constructional features of multiple-disc system using recycling methods of aided design and research were suggested.

The preferred modelling process of multiple disc grinder, and characteristic of milling indicator, makes possibility to design milling constructions with regard for cutting eg. materials, machine process parameters, and milling space conditions.

The results of this study, confirm the complex influence of different quantities, and factors on shredder's characteristics, and support the claim, that effective solution can only be achieved, if we respect deeply all the interdependence, and interrelation among construction elements. Further intensive studies are being conducted into recognition of relationship between constructional features of mill's functional systems and useful energetic characteristics using computer aided design and research systems.

Constructional characteristics of multi-disc plastic in recycling shredding assembly can be optimised on the basis of analysis of instantaneous and long-term quasi-shearing loads that accompany shredding of polymers in recycling. The proposed construction modelling methodology results from a systematic approach to the new milling process. It facilitates, therefore, an orderly derivation of versatile models, most appropriate for the particular researched processes. The development of construction models begins with the selection of coordinate systems.

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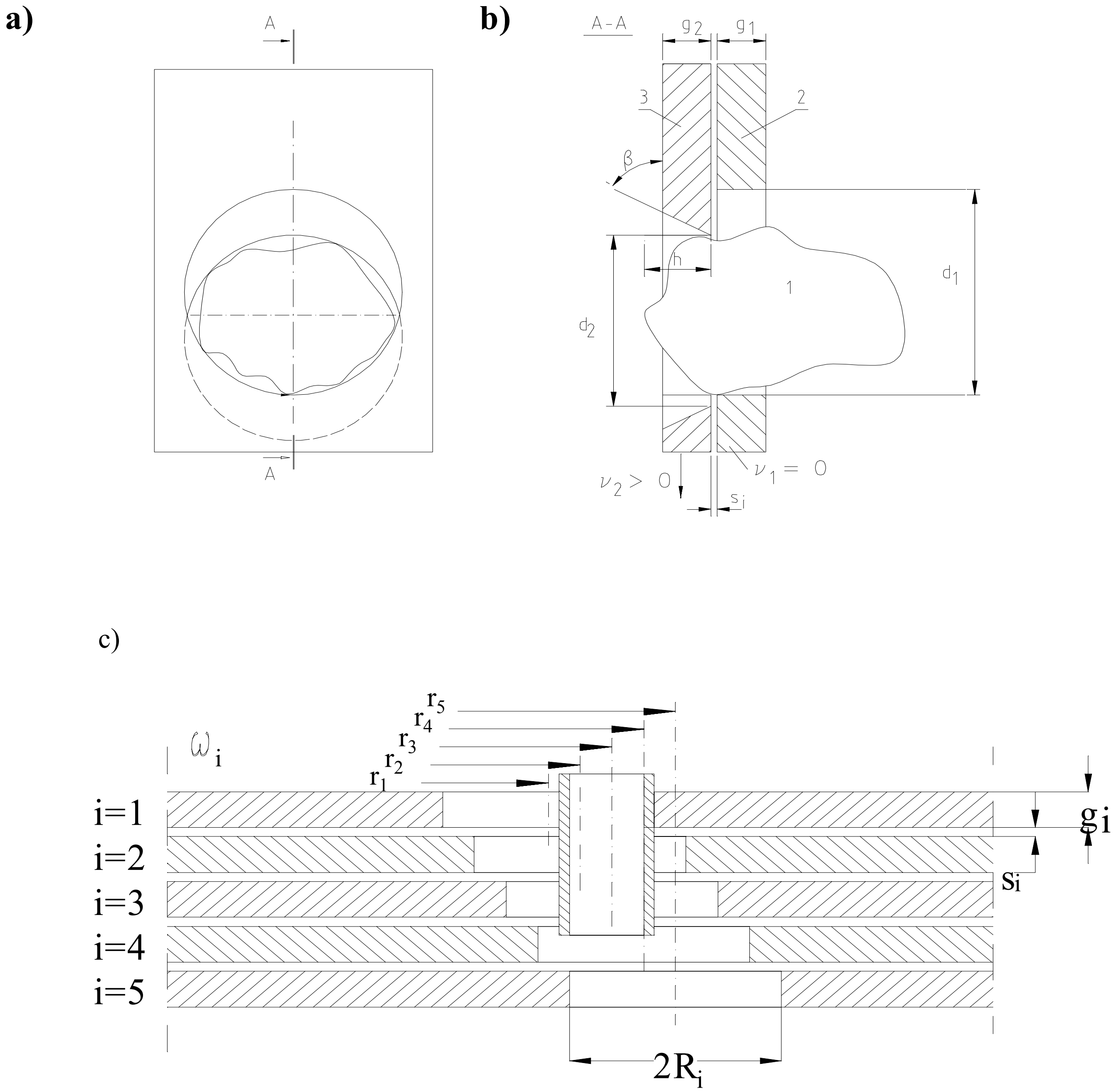


Fig. 1. View and cross-section of quasi-shearing area; a) front view, b) transverse view, c) quasi-shearing discs assembly; 1- comminuted material, 2- stationary discs, 3- rotating discs, β- angle of blade, s_i– gap (slot). between discs, g_1, g_2,g_i - thickness of 1st, 2nd and the ith disc, respectively, d_1- diameter of hole in stationary disc ($2R_i$), d_2 - diameter of hole in rotating disc.

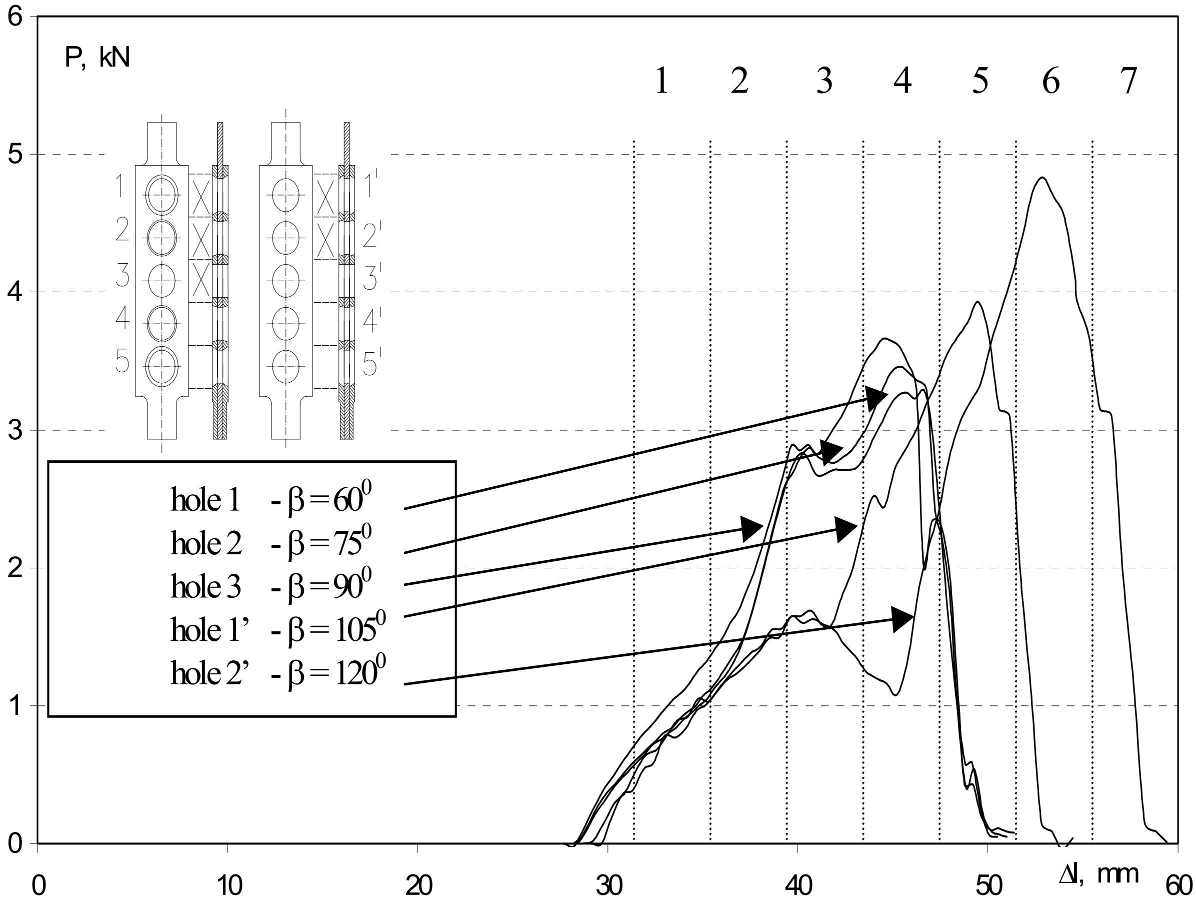


Fig. 2. Curves of force P quasi-shearing in function of slats dislocation Δl for different values of blade angle β. Material: PE-LD-pipe, outer diameter D_z=20 mm, thickness of pipe g=2 mm. Speed between slats v_r=2mms^{-1}.

Table 1: Influence crystallinities on properties of physical polymer materials

Feature	**Polymer crystalline**	**Polymer amorphous**
Thickness	Higher	Lower
Optical Properties	Hazy(misty) to opaque	Transparent even at considerable thicknesses
Mechanical Properties	Large tension strength, hardness, low impact strength and elongation(fullering)	Large elongation(fullering) and impact strength, smaller tension strength
Thermal Properties	Sharp point of fusing(melting), higher resistance temperature	Range of temperature fusing(melting), low resistance thermal
Solubility	Made difficult	Good
Contraction at cooling	Large	Slight

Table 2 : Physical properties of polymer materials (Macko, 2000)

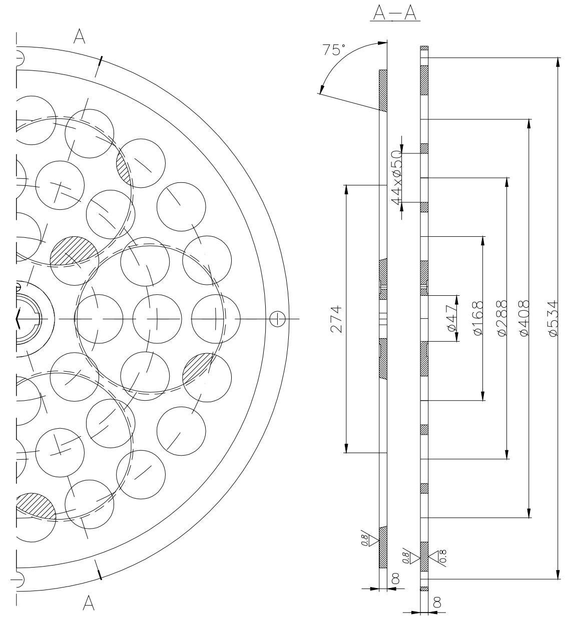
Property	PE-LD	PE-MD	PE-HD
Thickness (g/cm^3)	0,915 - 0,930	0,930 - 0,940	0,940 - 0,968
Softening point (°C)	102-112	110-120	125-135
Yield strength (MPa)	6,2 – 11,5	10 - 19	25 – 40
Tension strength (MPa)	6,9 - 16	8,7 - 21	25 – 45
Strength on quasi-shearing (MPa)	4.8 – 7,2	---	9,2 – 11.6
Elongation(fullering) (%)	100 - 800	50 - 600	50 – 1200
Modulus of elasticities at tension (MPa)	102 - 240	205 - 370	800 – 1200
Hardness A/V scale Shora D	40 - 50	45 - 60	60 - 70

Table 3 Proprieties of select package foil from polymer materials

Foil	Thickness (g/cm^3)	Tension strength (MPa)	Strength on quasi-cutting (MPa)	Elongation (fullering) (%)	Modulus of elasticity (MPa)	Impact strength (Nm)	Opacity
PE-LD	0,918-0,928	9-19	4,8-7,2	250-600	140-300	0,7-1,1	4-10
PE-LLD	0,917-0,928	24-56		400-800	175	0,8-1,3	6-20
PE-HD	0,940-0,965	21-52	9,2-12,6	10-500	875	0,1-0,3	25-50
E/VAC	0,94	21-28	-	350-600	40-100	1,1-1,5	2-10
Ionomer	0,95	25-38	-	300-600	70-450	0,6-1,1	1-15
PP	0,90	25-70	17,6-24,8	450-800	700-100	-	-
OPP	0,905	175-210	-	60-100	1500-2400	0,5-1,5	3
OPET	1,4	175	-	70-100	3000-4800	2,5-3,0	4
PA	1,14	49-125	-	250-500	1600	0,4-0,6	2
OPA	1,14	175-210	-	70	2300	-	1-2
PVC	1,21-1,38	14-70	25,2-31,2	5-500	150-2300	1,2-2,0	1-2
PVDC	1,6-1,7	55-150	-	40-100	350-1000	1,0-1,5	2
E/VAL	1,2	9-12	-	220-280	2200	-	-

thickness of discs, g_1, g_2=8mm
slot between discs, s_i=0,1mm
diameter of holes in discs, d_i, $2R_i$,
cutting-edge angle of transporting-grinding holes (γ_i, β_i=75^0, 90^0),
circumferential (pitch circle) of holes t_{oi},
radial pitch of holes, t_{ri},
roughness of outer disc surface, R_{ai},
outer disc diameter, D_{zi}=612mm,
outer diameter of holes in discs, D_{zi}, r_i.

Geometrical properties of the structure of shredding assembly



Geometrical features of two neighbouring-disc

Fig. 3. The process and machinery parameters of multiple-disc milling