MECHANICAL LOAD DURING SHREDDING OF TOUGH-PLASTIC MATERIALS WITH A TWO-SHAFT SHREDDER

Malina Ivanova

University of Mining and Geology "St. Ivan Rilski", 1700 Sofia; malina_vatz@abv.bg

ABSTRACT. This article is dedicated to the forces and moments that are applied during shredding of tough-plastic materials. A practical task is solved, which determines the magnitudes and directions of the forces and moments necessary for shredding of a particular type of waste, for the purpose of their further use. It includes two directions. In the first direction, sample values of forces and moments are calculated. The equations describing the mechanical processes under operating conditions are solved. In the second direction, the graph of applied forces and moments is analysed.

Keywords: forces, moments, tough-plastic materials, two-shaft shredder

МЕХАНИЧНО НАТОВАРВАНЕ ПРИ РАЗДРОБЯВАНЕ НА ЖИЛАВО-ПЛАСТИЧНИ МАТЕРИАЛИ С ДВУВАЛОВ ШРЕДЕР

Малина Иванова

Минно-геоложки университет "Св. Иван Рилски", 1700 София

РЕЗЮМЕ. Статията е посветена на силите и моментите, които се прилагат при шредиране на жилаво-пластични материали. Тук е решена практическа задача, с която са определени големините и посоките на силите и моментите, необходими за раздробяване на определен тип отпадъци, с цел по-нататъшната им употреба. Тя включва две направления. В първото направление се изчисляват примерни стойности на силите и моментите. Решени са уравненията, описващи механичните процеси при работни условия. Във второто направление се анализирани приложените сили и моменти.

Ключови думи: сили, моменти, жилаво-пластични материали, двувалов шредер

Introduction

The use of recycled or waste products of tough-plastic materials, which replace natural mineral forms as a source for making materials with practical applicability, greatly alleviates environmental pollution. This creates more comfortable living conditions for the population and protects it from a number of factors harmful to life and health. A number of productions from the construction, mining and chemical industries adhere to the model of sustainable development.

Waste rubber, plastic, electronic equipment, kevlar, paper, etc. are considered as tough-plastic materials.

European and national waste management policies provide for measures to be taken to increase the recycling and recovery of waste. Thus, it is of particular importance to study and improve the various machines for shredding the different waste streams. In the EU, the requirements for waste management, e.g. of packaging waste, are defined by

Directive 94/62/EU on Packaging and Packaging Waste. The Directive has been transposed into the Bulgarian legislation through the Waste Management Act and the Ordinance on Packaging and Packaging Waste. There is also a National Waste Management Plan for the period 2014-2020 defining the following goals for packaging waste:

- Not less than 60% of the weight of the packaging waste must be recovered;
- Not less than 55% and not more than 80% of the weight of the packaging waste must be recycled.

The fulfilment of these goals can be assisted by the use of shredding machines (shredders).

The process of reducing the size of materials of different origin to the desired size under the action of external forces is called shredding. The technological purpose of shredding depends on the subsequent processes and processing stages or on the purpose of application of the products from shredding. Shredding is the first step in reducing the geometric sizes of the material during recycling.

Shredders have a very wide field of application: from hazardous and medical waste to tires, from plastics, wood, textiles and paper to metals, from construction and household waste to electronic scrap.

The management of waste streams is a challenge because of the high value of the numerous manual operations, high transportation costs and the negative impact on the environment.

Object of study

The object of study in this work are the necessary forces and moments for shredding of waste products from tough-plastic materials with a two-shaft shredder.

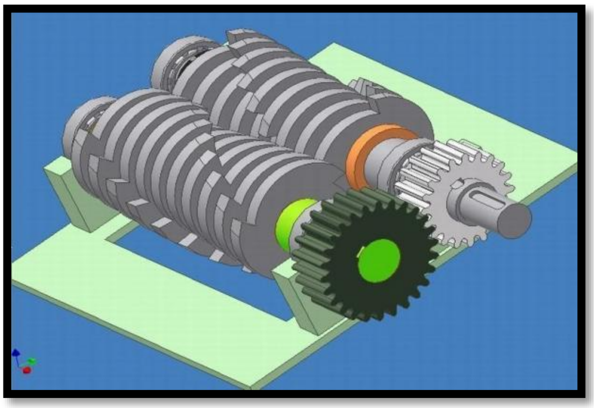

Fig. 1. Diagram of a shredding chamber of a two-shaft shredder

Fig. 1 shows the shredding chamber of the two-shaft shredder for shredding of tough-plastic materials, in which the permissible compressive stress of the destructed elements is σ_H = 25 MPa (Borshchev, Dolgunin, Kormilytsin, Plotnikov, 2000), and its productivity is 10 t/h. The granularity of the product obtained after shredding is (0 – 50) mm.

As the material is tough-plastic, shredders working on shear and pressure are used (Sirotyuk, 1999).

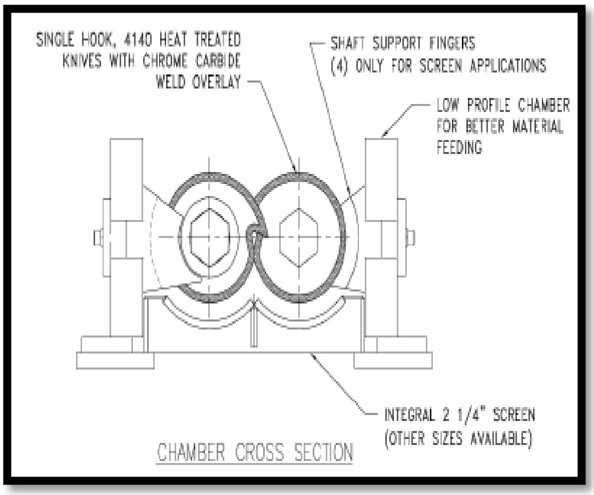

Fig. 2. Diagram of shredding with a two-shaft shredder

Fig.2 presents a diagram of shredding of simultaneously working "destructive" teeth (Tokarskiy, Yankiv, 2008).

The determination and calculation of the necessary forces and moments for shredding of waste products from tough-plastic materials with a two-shaft shredder will be carried out using the following data:

- maximum compressive strength of the destructed elements – 25 MPa;
- approximate dimensions of the area of the chamber - 900 x 700 mm;
- power supply of the shredder – flow, discrete, operator-controlled;
- separation and loading of the shredded material - flow, continuous, automatic;
- machine drive - hydraulic, from a pump / hydraulic motors / cylinders and internal combustion engine / electric motor;
- approximate power of the drive – 100 кW.

Concept for a model study

The purpose of the study is to determine and calculate the necessary forces and moments for the shredding of waste products from tough-plastic materials with a two-shaft shredder, which is presented on Fig.3.

It was found that the pressure, which each carbide cone on the disc teeth exerts on the destructed material, is 44 MPa. It is nearly 2 times the disruptive tension of 25 MPa (Borshchev, Dolgunin, Kormilytsin, Plotnikov, 2000). The pressure is assumed as applied to an area of the tooth with a diameter of 30 mm. It is transformed into radial forces on the knives, respectively torques (torsion moments) on the shredder shafts (Pisarenko, 1993).

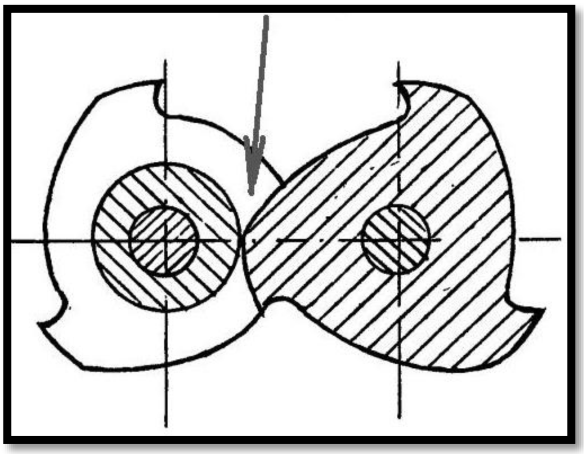

Fig. 3. Force and moments during shredding

Under the accepted condition for 3 simultaneously working "destructive" teeth (Vatskicheva, 2016), the nominal torque of each shaft at 25 rpm - 40 kN.m - is determined. In this case, the appropriate heliocentric -type reducer is PG 3501 with gear ratio i = 4.1. Accordingly, the drive hydraulic motor is a radial piston one, with constant flow-rate, of type *IAM.1600 H, with a maximum speed of 250 min-1 and a torque equal to 7860 N.m at a pressure of 300 bar*.

The end conditions reflecting the mechanical load when operating the steel structure (Borshchev, 2004, Tavakoli et al. 2008) include the following parameters:

- input power: P_{inp}= 90 кW;
- rpm (revolutions) of the working shaft:
n_V= 25 min^{-1};
- frequency of rotation of the working shaft:
$\omega_V = \frac{\pi . n_V}{30} = 2.62 rad/s;$
- torque of the working shaft:
$M_v = \frac{P_{вх}}{\omega_V . \eta} = 35 \ kN.m,$
where η=0,98 is the efficiency of the transmission;
- disruptive tension of the tough-plastic material:
$\tau_s = 60$ MPa;
- shear force by one knife
$F_s = \frac{M_V}{3.0,175} = 66.7$ kN:;
- moment of resistance of shredding by 1 knife: $M_{S1} = F_s . l_s = 11.67$ kN.m.

The mechanical load during operation of the structure is presented on Fig.4 (Tokarskiy, Yankiv, Siryk, Gochko, Kosenko, 2003).

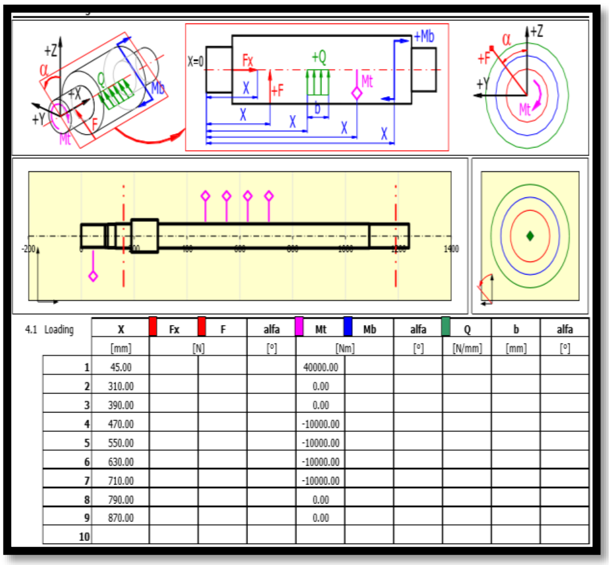

Fig. 4. Mechanical load during shredding of tough-plastic materials

The required power W to drive the shredding shafts is determined by the formula (Vatskicheva, 2017):

$$W = \frac{P_b.\mu.S_t.\frac{D_t}{2}.Z.n_v}{9554} \quad (5)$$

$$W = \frac{25.10^6.2.6.10^{-4}.0,15.8.25}{9554}$$

$$W = 94.2\ kW,$$

where:

- P_b is the tension for shredding of the tough-plastic material - 25 MPa
- S_t – the maximum contact area of each destructive tooth ~20 x 30 mm or $6.10^{-4}m^2$;
- Z - number of simultaneously working discs - 8 / 4 from one of the shafts and 4 from the other, with a total length along the axis of the shafts - 320 mm, which is greater than the maximum size of waste materials /
- D_t – diameter of the cutting discs 175 mm / distance of the teeth from the shaft axis /;
- n_v – rpm (revolutions) of the shafts 25 min^{-1};
- μ – coefficient of power reserve equal to 2.

Numerical results

Table 1 summarises the results of the power (force) load during shredding of tough-plastic materials.

Table 1. *Change in the power load during shredding*

№	F_y	F_z	Alfa
	[kN]	[kN]	[°]
1	22.81	62.68	20
2	23.90	62.27	21
3	24.99	61.84	22
4	26.06	61.40	23
5	27.13	60.93	24
6	28.19	60.45	25
7	29.24	59.95	26
8	30.28	59.43	27
9	31.31	58.89	28

Table 2 summarises the results of the momentary (instantaneous) load during shredding of tough-plastic materials.

Table 2. *Change of the momentary load during shredding*

№	x	M_t	M_b
	[mm]	[kN.m]	[kN.m]
1	45	40	10.97
2	310	0	10.90
3	390	0	10.82
4	470	-10	10.75
5	550	-10	10.66
6	630	-10	10.59
7	710	-10	10.49
8	790	0	10.40
9	870	0	10.31

Conclusions

The results of the model studies conducted justify the following conclusions:

- the study determined the numerically necessary forces and moments for shredding of waste products from tough-plastic materials with a two-shaft shredder;
- the radial forces on the knives resulting from the disruptive pressure applied to a surface from a tooth surface are included;
- the nominal torque is obtained under a condition for three simultaneously working "destructive" teeth.
- a solution is proposed to a practical problem related to determining the mechanical load during shredding of tough-plastic materials with a two-shaft shredder;
- the magnitudes and directions of forces and moments for shredding of a particular type of waste are determined;
- the problem (task) involves solving the equations describing the mechanical processes under operating conditions and analysing the applied load.

References

Borshchev, V. Y. 2004. *Equipment for crushing of materials.* State Technical University Tambovsky, Moscow

Borshchev, V. Y., V. N. Dolgunin, G. S. Kormilytsin, A. N. Plotnikov. 2000. *Technique of processing of brittle materials*. State Technical University Tambovski, 40 p.

Pisarenko, G. S. 1993. *Resistance of materials.* Higher School, Kiev

Sirotyuk, S. V. 1999. *Mechanisation of cork and storage of products of plant grower/Course of Lectures.* LDAU, Lviv

Tavakoli, H., S. S. Mohtasebi, A. Jafari. 2008. Comparison of mechanical properties of wheat and barley straw. – *Engineering International: CIGR Journal, 10*, 1–9.

Tokarskiy, Yu. M., V. V. Yankiv. 2008. *The mechanical transmissions, calculation and constructing.* Navsh. Posib., New World, Lviv

Tokarskiy ,Yu. M., Yankiv V. V., Siryk Z. M., Gochko M. O., Kosenko I. E., 2003. Calculations of mechanical transmission on computer/Navsh. Posib. Lviv, LDAU.

Vatskicheva, M. 2016. Calculations and verifications of shredding chamber of two-shaft shredder for crushing of concrete, rubber, plastic and wood. – *Proc. International Scientific Conference "High Technologies, Business, Society", 4 (190)*, 49–52.