Plastic Waste Shredder

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Abstract. Used plastics are all around us. Their production is excessive and presents a big problem today and an even bigger problem for the future. They are used very often for their positive qualities. Just as the pros also have their negatives. One of the biggest drawbacks is the decomposition time of this kind of a waste. Separation, collection, and recycling should be taken for granted, but they are not. Plastic waste management is a very inefficient process because plastics take up a lot of space at low weight. The use of crushers, the reduction of waste should play a major role; especially in reducing the logistical costs of plastic handling and preparation for further recycling steps. This article describes the possible design of a plastic waste shredder, with key parts and visualization of a machine. An important part is the solution of the crushing mechanism itself, which plays a key role in the operation of the equipment. This project was solved at the Department of Design and Machine Elements.

Keywords: Plastic Waste · Shredder · Recycling · Construction Points Design

1 Introduction

The aim of this paper is to inform the professional public with the possible design of a machine for processing plastic waste. By shredding plastic waste, it is possible to protect nature and create economic benefits. The proposed crusher is able to process plastic waste and thereby reduce logistic costs in any manipulation with it. By shredding, the waste gets added value and can be moved further in the recycling chain and bring economic benefits to the waste processor.

Recycling itself is a complex process in which waste is collected, sorted (separate types of waste, in our case plastics) and subsequently proceeded to further processing processes. In the Slovak Republic, the collection yards are the place where waste is collected, collected and subsequently proceeded to further separation. The operators of such facilities are towns, villages and private companies, with the technical equipment of such facilities, sorting and processing processes slightly different. Small collection yards can be said to act as a waste collection point, with the processing process being small (composting) or almost none. For larger collection yards it can be said that they belong to the chain of processing facilities e.g., large metal collectors are allowed to dispose of old wrecked cars ecologically. The processing activities of these facilities are regulated by law. The legislation also limits the functioning of equipment such as the

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proposed shredder within the yard. For example, if the amount of processed material (of different kinds) at the collection yard does not exceed 50 tones, the collection yard does not fall into the category of processing facilities and does not have to meet other criteria [1]. The process of collecting and processing should be optimized [2].

At present, there is a lot of ambient pressure to increase the proportion of recycled waste. This measure will reduce the yield of crushed plastic waste because plastic bottles have been one of the most widely used types of plastic waste. However, the device can be used to crush other types of plastic, it is only necessary to consider its greater versatility and expand its use that is crushing several types of plastic waste. A very important aspect is the controllability of the size of the crushed material. For this purpose, a means for controlling the size of the processed material to be processed will serve. The simplest means of regulating is the presence of a screen that fulfils this function. The aim of the study was plastic waste shredder.

2 Materials and Methods

2.1 Requirements and Shredder Scheme

Restrictive conditions need to be determined in design, any new equipment. As in the concept, the equipment should operate in the conditions of small collection yards, where it would save the logistical costs, most at the next waste disposal. A very important requirement is the low maintenance and operating costs, which should, in turn, contribute to the creation of added value for the collection yard.

One of the other important conditions is the controllability of the size of the pulp. For some types of plastics, this is a very important aspect, because, respectively, the processing or the plastic pre-crushing can form a pre-treatment process for further waste treatment, thus saving time and associated costs. By crushing we can create a more homogeneous secondary raw material structure. Of course, it must be true that the crushing degree cannot be very high, which means that the achievement of the required crush size can be achieved by better and faster multistage crushing.

An important requirement is the amount of treated waste. If the plant is to operate in a small collection yard, at an average recycling rate of about 6.2 kg per capita, it

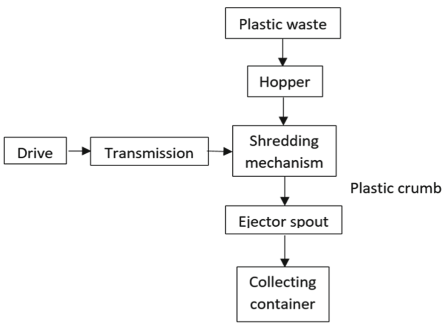

Fig. 1. Block diagram of the crusher [3].

is estimated that 5 000 people sort out about 32 tonnes of plastic waste, far below the 50 tons of processed waste [3]. The block diagram of the device (see Fig. 1) shows how the device will operate and how the crushing process will take place is important part of construction process. Plastic waste by being thrown through the hopper into the shredding mechanism will achieve the desired shape and size, going out through the hopper into a collection container or some other bag filling system [4]. The shredding mechanism is driven by gearbox that regulates the speed.

2.2 Crushing Mechanism Variants

Primary or secondary material is not always ready for the next steps in technology processes. The choice of processing technology tends to be associated with material properties. Processes preparing material for further use fall into the category of preparatory processes. Crushing and grinding, which will be carried out by the constructed equipment, falls into the category of dressing processes and forms so-called preparation phase. The term crushing refers to the interruption of bonding within the body and the formation of particles of different grain sizes (Table 1) [3].

From the point of view of fulfilling the main function of the device, that is to say, the most important question the crushing of the material is the solution and selection of the right method of crushing. With its specificity, plastic waste is not so complex to crushing as other types of materials (Fig. 2) [3].

By searching the market and providing solutions, several possible design solutions were selected for the crushing mechanism of the proposed device. The simplest solutions include a single rotor shredder and a knife mill (Fig. 3). In the first variant, cutting discs are placed on the roll and form a cutting surface together with the wipers screwed into the housing. The cutting plates are stepped over the circumference of the cylinder. The

Table 1. Type of crushing according to grain size.

Type of crushing	Grain size
Medium crushing	≥25 mm
Fine crushing	<25 mm
Grinding	<1.25 mm
Fine grinding	<0.008 mm
Ultra-fine grinding	<0.001 mm

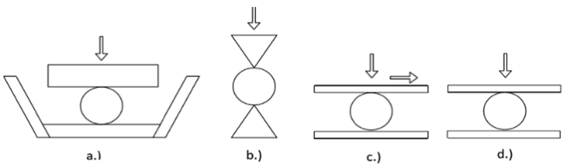

Fig. 2. Basic principles of crushing: a) crushing, b) splitting, c) trituration, d) comminution [3].

sieve under the cylinder creates space and allows the crushed material to return to the crushing process, controlling the size of the crushed material. The speed must be less so that the crushing process is correct and there is no material bouncing from the crushing mechanism. In a knife mill the crushing process is caused by a knife screwed to the mechanism housing and a rotor portion on which the other blades are oblique. The sieve creates space for the shredding process until the material reaches the desired dimensions. For proper operation, the rotor must have a high speed to achieve the necessary cutting force.

Other variants of the solution are single shaft and double shaft shredder (Fig. 4). The first mentioned mechanism consists of a shaft on which are shredding knives embedded. Between knives are gaps and in these gaps are so-called wipers, that are spilling out of the housing of the shredding mechanism. Knives placed on the shaft are arranged in a helix, thus creating the effect of "pulling" the material into the grinding mechanism. The whole mechanism is driven by an electric motor and reduced by a gearbox for reliable operation. The speed of shredding mechanism must not be high, otherwise the crushing process would not occur properly and could even clog it [5].

The equivalent to this solution is a two-shaft shredder (more complex) which, like the previous variant, crushes the material, but the main shredding process takes place between the two knives, while engaging them. The solution was after points rating selected and the two-shaft shredder had the highest number of points. From the point of view, the production difficulty, it is the most demanding of all variants, but the process of shredding will be continual and evenly, which is important for further economic exploitation of the secondary raw material.

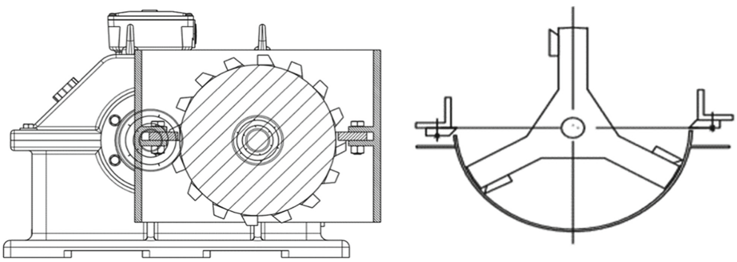

Fig. 3. Single-rotor shredder and knife mill [3].

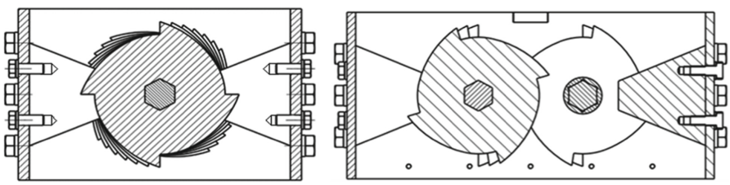

Fig. 4. One shaft and double shaft shredder [3].

3 Results and Discussion

Plastic waste processing equipment should meet the requirement sheet and in essence, cheap, unassuming for maintenance, operational and beneficial for the user. Chapter 3 describes the main key points in designing the device construction. The crushing mechanism often work in extreme conditions. They are especially important to design points, from which the whole construction of the device depends on.

3.1 Size of Crushing Chamber

The size of the crushing chamber is directly linked to the requirement for processing the amount of plastic waste throughout the year. When looking for a consensus, it is necessary to build a device similarly with devices on the market and dimension are similar to the equipment. The machine would be used as effectively as possible and the service would be economical. By comparing the market, it has been found that the 400 × 400 size crushing chamber is large enough to process the required quantity.

3.2 Size of Crushing Force

The most important part is determining the crushing force. An empirical method was sought for the economic demands of the experiments, which would take into account the mechanical properties of the plastics in the design of the crushing device. Using equation: (1), (2), (3) it can be said that the force can only be estimated approximately.

$$F_S = S * \tau_{Ps} * 0,67 \tag{1}$$

$$F_S = S * \tau_{Ps} \tag{2}$$

$$F_S = \frac{s^2 * \tau_{Ps}}{2 * tg\varphi} \tag{3}$$

The forces F_S depend on the cutting area *S,* the shear strength τ_{Ps}, the thickness of the cut material *s*, the angle resulting from the cutting tool geometry φ.

3.3 Crushing Knife

One of the key points of the device solution is the design of crushing knives. Several market variants of knives have been identified by the market research, with three-point and four-point tools being the most common. Replaceable cutting discs that have several advantages have been widely used. Replaceable cutting discs that have several advantages have been widely used.

The most important of these is the interchangeability, respectively quick repairability of fractured cutting knife. A simpler design of the cutting knife with and without removable cutting plates is from cutting tools taken over (Fig. 5).

The choice of material for these variations would vary. In the first variant, the feature is that it will not change frequently, so a wear abrasion resistant steel (Hardox 400, 500)

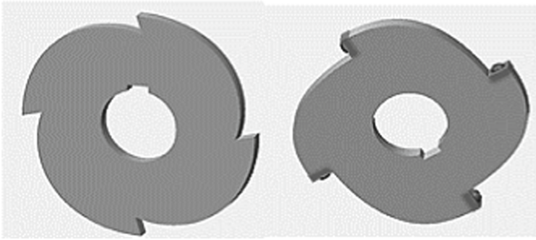

Fig. 5. The knife without and with cutting plates [3].

would be appropriate. If option two has been selected, with replaceable cutting discs, the choice of well machinable steel and easily chemically heat treatable steel is needed. For example, with cementation, we increase the surface abrasion resistance and maintain core toughness (steel E295).

3.4 Electric Motor and Gearbox

The choice of the electric motor is a very important part and the operation of the shredding mechanism depends on it. Of the total number of knife shots p_{knife}, results in the requisite crushing force F_C, (4). By selecting the size of the crushing tool R_{str}, we are able to determine the grinding moment M_k at the end of the knife, respectively his plates (5). Using Eq. (6), we are able to determine the minimum power required to shredding the material P_{EM} from grinding moment M_k and sped of the motor per hour n_{ot}.

$$F_C = F_S * \mathrm{p_{knife}} \tag{4}$$

$$M_k = F_C * R_{str} \tag{5}$$

$$P_{EM} = \frac{M_k * n_{ot}}{9550} \tag{6}$$

The power required to drive the mechanism from the calculation is a minimum value. When transmitting power through the gearbox, losses occur, characterized by the efficiency of the transmission ηP. When using a tapered gearbox, the efficiency is a normal value of 0.98. In the design, it is necessary to take into account the presence of a pair of rolling bearings on which the shaft is mounted, which represents the value $\eta L =$ 0.995–0.990. This power needs to be at least 10–20% higher due to the power reserve of Eq. (7).

$$P_M = P_{EM} + 0,2 * P_{EM} + P_{EM} * (1 - (\eta_L * \eta_P)) \tag{7}$$

The advantages of a tapered gearbox (Fig. 6) are to minimize the space and storage requirements of the device while maintaining constant running even when changing loads. The gear ratio will be steady and will not interfere with the diversity of the crushed material, the running will be stagnant and will not stagger. A suitable accessory is the protection of the electric motor by overloading.

3.5 Reactions in Bearings and Bearings Lifetime Calculation

The next key points in design of the device are the dimensioning of the minimum shaft diameter and the calculation of the reactions to determine the bearing life cycle. The load torque on the shaft is determined by the formula (8), with the maximum load from the motor part, that is, the maximum possible torque that the electric motor can produce. The moment is the same in both planes. The shaft is loaded essentially on the parts of the crushing mechanism by the individual forces we have included in the resultant as a continuous load. We had to determine the shaft tension in two planes (Fig. 7, Fig. 8).

$$M_{EM} = \frac{P_M * 9550}{n_{ot}} \tag{8}$$

The magnitude of the continuous load is determined, by the size of the total load force and the length of the shaft on which the forces are stored. Since the shaft is solved in two planes, the continuous load needs to be solved in two planes (9, 10). In the vertical plane

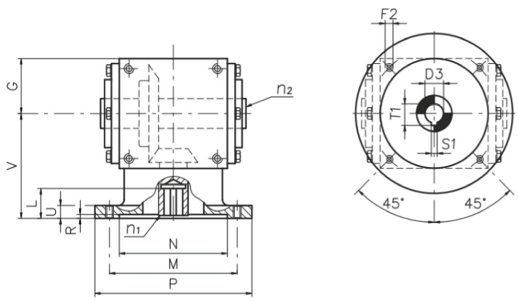

Fig. 6. Conical gearbox.

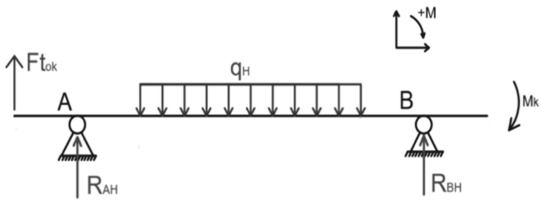

Fig. 7. Horizontal plane with loads [3].

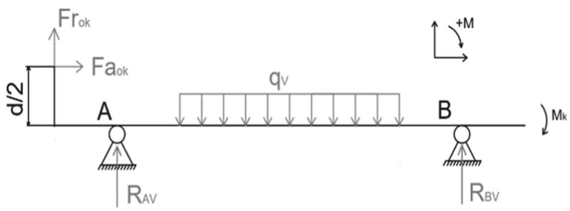

Fig. 8. Vertical plane with loads [3].

(9), in addition to the total cutting force, there is also a continuous load (10) resulting from the number of knives n, the weight of the knives m_n, the gravitational acceleration g and indirectly proportional to the length of the load a.

$$q_H = \frac{F_C}{a} \tag{9}$$

$$q_V = \frac{F_C}{a} + q_G \tag{10}$$

$$q_G = \frac{n * m_n * g}{a} \tag{11}$$

A gear engagement is present at the shaft end to transmit the torque from the drive shaft. There are forces in the gearing. The solution must be in two planes, in vertical (circumferential force F_t), and horizontal (radial force F_r). Reactions of the forces are in the supports of our beam. In the horizontal plane, these are the R_{AH}, and R_{BH} components, and in the vertical plane, the R_{AV}, and R_{BV} components.

The responses are then used to calculation of the bearing life cycle (13). The service life depends on the speed n, the basic dynamic load rating C and the equivalent load P_r. The equivalent load (5) is dependent on the acting radial force F_r, the axial force F_a, the coefficient of dynamic radial load X, the dynamic axial load coefficient Y and the coefficient characterizing the bearing type p.

$$P_r = X * F_r + Y * F_a \tag{12}$$

$$L_{10h} = \frac{10^6}{60 * n} * L_{10} = \frac{16667}{n} * \left(\frac{C}{P}\right)^p \tag{13}$$

The bearing must have a longer life than calculated, otherwise it does not meet the service life requirement.

3.6 Clutch

One of the other key parts is the choice of a coupling connecting the shaft to the gearbox. Chosen was the KBK/BI-10-1600 torque overload clutch, which is capable of transmitting torque and also serves to dampen torque peaks. In the case of a higher load, than the clutch, the torque transmission is interrupted, and the driving part and the driven part are twisted independently. Re-connection of the shafts with the shaft occurs after returning the torque below the maximum torque that the clutch transmits. Depending on the size, this type of coupling can transmit torque from 10 to 1 600 Nm and is heat-resistant in the range of −30 °C to +120 °C.

3.7 Description of Final Construction

The constructed device consists of several main parts. These include crushing chamber, shredder shafts, gearbox drive, clutch, sieve, ejector spout plates, hopper plates and frame (Fig. 9). The crushing chamber itself consists of 4 welded works. They are screwed

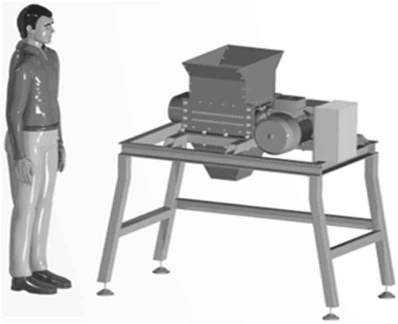

Fig. 9. Machine with operator [3].

together and bearing housings are screwed to them. Shafts that crush waste are folded from knives, which are placed in a helix, thus forming a “self-pulling” effect of the device, for the crushing process. The spaces between them are filled with delimitation rings that define the distance between the two knives and form a space for engaging the knife of the second shaft. The shafts are protected against slipping of the blade of with MB washers and KM nuts at the ends of the shaft working section. Also included the crushing chamber is a sieve which is screwed to it. By its design, it regulates outgoing crumbs and by its arrangement, it allows to regulate or return the shredded material into the shredding process. The hopper and ejector spout are made from steel plates and screwed to the crushing chamber.

The drive and gearbox are screwed through the plate to the frame of the construction. The overload clutch protects against overloading of the device against high stress and thus protects the knives of the crushing mechanism against damage. By selecting a gearbox with a tapered gear, we have minimized the space required for the machine frame. The frame constitutes the supporting part of the device structure and the shredding mechanism being screwed together with the entire shredding chamber for better assembly. At the same time, it forms a base for the drive of the shredding mechanism it is engine and transmission. The base part of the frame is formed by a weld of four UPE profiles, to which are profiles with square section welded and form the above ground for the crushing chamber. In the frame are drilled holes for the crushing chamber. On the bottom of the bent legs, there are plates with weld nuts for adjustable and anchoring legs. The control box is designed for operation and screwed to the frame.

4 Conclusion

Plastic is a problem for ecology, and everyone should pay proper attention to recycling. The European Union is pushing for an increase in the share of material recycling and the creation of a circular economy [4].

Plastics logistics is an expensive activity and very inefficient. In terms of volume to weight ratio, the coefficient of use of the car for the removal of plastic waste is very low. It is necessary to teach people to process plastics to shrink already during the collection of plastic waste. By the presence of recycling systems in small collection yards, we can improve the plastic waste logistics process. By sorting and crushing any plastic waste, better use of the logistics chain can be achieved. Sorted plastic pulp-flakes can already be treated as a secondary raw material suitable for further processing in the recycling process. Such a step can help increase the protection of our environment and help to recycle [5].

The mere inclusion of a shredder for small plastic yards would result in the need for design, resp. purchase of the necessary additional accessories, which would create jobs and support the economy in the field (engineering-design production). The accessories can be understood as a system of conveyors, conveyors capable of filling large bags, stairs, barriers, and other supporting elements.

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