Computer-aided Eco-design Grinding Machines using Software SolidWorks Sustainability

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Abstract. The publication presents selected results of an attempt to link material and environmental valuation with the design of technical objects in accordance with the requirements of the concept of Life Cycle Management. The goal of this action was to develop environmental analysis of the conical shredder using the SolidWorks Sustainability application. The assessment of environmental impacts included: extraction of raw materials, material processing, production of parts, assembly, use of the product, landfill storage and transport. Based on the results of the analysis, the potential emission levels were determined: CO_2, SO_2, PO_4 and guidelines for the environmental development of technical facilities were proposed.

1 Introduction

According to the PKN-ISO/TR 14062:2004 standard, eco-design is understood as the integration of environmental aspects into product design and development [1]. Therefore it should not be seen as a separate procedure, but as a complement to traditional design. In the classical approach to design, environmental problems did not play an important role. The main aspects taken into account were strength and technical parameters, functionality, costs, safety or ergonomics. Ecodesign drew attention to two equally important elements of design assessment, namely environmental impact assessment and the perspective of the whole life cycle.

One of the most popular ecodesign tools is environmental life cycle assessment (LCA). Although LCA is not the only technique for environmental management, it has many characteristics that determine its advantages. For example, the perspective of "from birth to death" (from-cradle-to-grave perspective). It ensures that no stage in the life cycle is missed. The method takes into account all ecosystems and their elements [2, 3]. Thanks to this procedure it is possible to assess the overall environmental impact and the consumption of environmental resources [4]. The LCA, on the one hand, normalizes data on the amount of introduced energy and materials, and on the other hand, the generation of pollutants (emissions to soil, water and air) and any waste within functional units that are related to

specific environmental media (soil, water, air) [5]. One of the applications designed for designers is SolidWorks Sustainability. It allows to estimate the life cycle of elements and mechanisms of machines and devices. The group of machines, which are subject to high environmental requirements are shredders [6]. Due to the fact that shredders are characterized by low efficiency of operation, the search for better, more pro-environmental construction solutions has been conducted for many years [7-12]. The shredding process can be realized in various branches, e.g. in the field of shredding wood and chips [13-15]. On the other hand, the quality of the shredding product determines the further processing susceptibility of plastics and quality of mixtures, e.g. [16].
The aim of the study is to evaluate the environmental impact of selected elements of the shredder for polymer products and waste, using SolidWorks Sustainability application.

2 Life cycle properties of the polymer waste shredder

The life of each shredder's working unit takes place in five basic phases: the formulation of the need, construction, manufacture, operation and post-use use [17]. In each phase, the respective systems aim to perform a separate action to achieve the desired effect.
The first phase - the formulation of the need, can take place in the sphere of production, services, consumption, etc. The need should be determined in such a way that ways of satisfying it are not suggested in advance [18,19]. After the formulation, it is evaluated. If it is not possible to satisfy the need by using an existing working group, action should be taken to create a new one.
The phases of formulation of the need and construction are the key stages in minimizing the harmful and increasing the positive impacts during the whole life cycle of the shredder's working units [20]. The formulation of a new need may take place after the end of the previous life cycle of the shredder and after its examination and evaluation, e.g. with the use of computer support [21]. The obtained results, identifying the main hazards and desired impacts, may give rise to a need to introduce innovative solutions for the construction and operation of the analyzed work unit [22-25].
The manufacturing phase is the production of the shredder assembly with the required properties, i.e. with the usable potential predicted in the project.
The exploitation phase is considered to be the most important phase of the working unit's existence, because during this phase it performs the tasks for which it was designed and produced [26].
The problem of the post-use development should be taken into account both at the stage of construction, production and operation. Due to the problem of depletion of natural resources, the most appropriate would be to reuse what can be reused for building new facilities [27]. As a result of such an approach, the concept of recycling has emerged, indicating the possibility of reuse of individual parts of the shredder working units.

3 Research methodology

The model of the shredder for polymer products and waste made in 3DCAD SolidWorks standard (Fig. 1) was used for the tests.

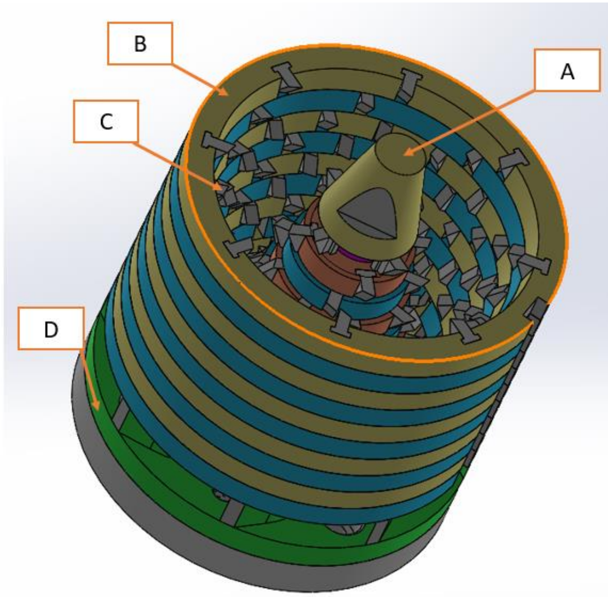


Fig. 1. Model of polymer product and waste shredder with com-ponents selected for environmental analysis; A - moving shaft with set of rings and knives, B - set of stationary rings with knives, C - single knife, D - bottom shield connected to moving shaft and equipped with throwing blades.

SolidWorks Sustainability (DassaultSystèmes SolidWorks Corporation) has a product lifecycle database created by the independent organization PE International [22, 27]. It exists since 2009 and is an excellent tool for assessing the environment that links LCA with engineering design. It is fully integrated with SolidWorks' CAD software, further introducing Life Cycle Assessment (LCA) based tools that measure the impact on carbon dioxide emissions (in kg $CO2$ eq), energy consumption (in MJ), air acidification (in kg $SO2$ eq) and water eutrophication (in kg $PO4$ eq) [28] throughout the shredder life cycle.

The first step of the test is to draw, in accordance with SolidWorks' handling principles, a 3D format element to be analyzed, i.e. a shredder for polymer products and waste. Then, in the tools tab, select the Sustainability function and run it, which opens up a range of possibilities for testing and evaluating the analyzed work team [20, 25]. In the first step, appropriate materials for building individual elements should be selected, initially by choosing a class and then a specific material. The program automatically generates the mass of a given element. The next step is to select the region in which the material in question was produced, the choice was Europe, Asia, India, Australia and North and South America. The same choice is possible when determining where the analyzed material will be used. The next window allows to determine the transport distance of the item, using rail, car, ship and/or plane, from the point of production to the place of localization. The whole procedure must be repeated for all the materials that build the individual elements of the work unit.

The main tool for eco-design in SolidWorks Sustainability is the environmental impact window. It is divided into four main categories: Carbon Footprint, Total Energy Consumed, Air Acidification, Water Eutrophication, each of which takes into account five areas of influence, namely material, production, use, transport and end of life, understood as post-consumer use [24, 25, 28]. One of the first inputs that users can enter into the software is the product material. The available input at the production stage includes the place where the product will be produced, the product's lifetime, the total electricity and gas it will consume, and the amount of product that will be disposed of in landfills. The program then allows you to enter detailed information on the transport and end of product life. As with other inputs, there is a default setting to help you who may not know the details of these choices.

After all the selections are made, the environmental impact is presented in categories: Carbon emissions (CO2), Total energy usage (MJ), Air acidification (SO4), Water eutrophication (PO4) [29]. After the modelling is completed, the results are made available as a full report.

The CML method has been adopted as a component of the LCA technique to estimate the environmental impact of a technical object in terms of: greenhouse gas emissions (kg CO2 eq), acidification (kg SO2 eq), eutrophication (kg PO4 eq) and energy consumption (MJ) [22-26]. Due to the nature of the conducted research, the graphic area is Europe. The shredder for polymer products and waste during the period of use of 100 man-hours was assumed to be the functional unit. The research was dividedintothreescenarios (Fig. 2.).

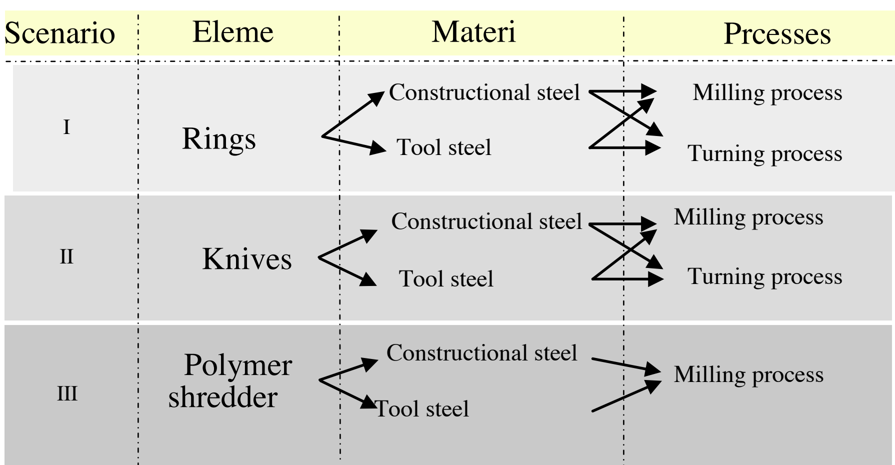


Fig. 2. Research plan including three life cycle assessment scenarios for polymer product and waste shredders.

4 Test results

Scenario 1

In the case of the first scenario, elements of the shredder's structure were considered, which consists of a set of 10 rings with a total weight of 6.29 kg. The first step was to compare the process of ring processing by milling made of two materials: structural steel S 185 and tool steel X40Cr14 (Fig. 3). In the second step, the process of ring turning treatment using the same materials was compared (Fig. 4). The total environmental impact of a set of ten shredder rings is presented in the final report (Fig. 5).

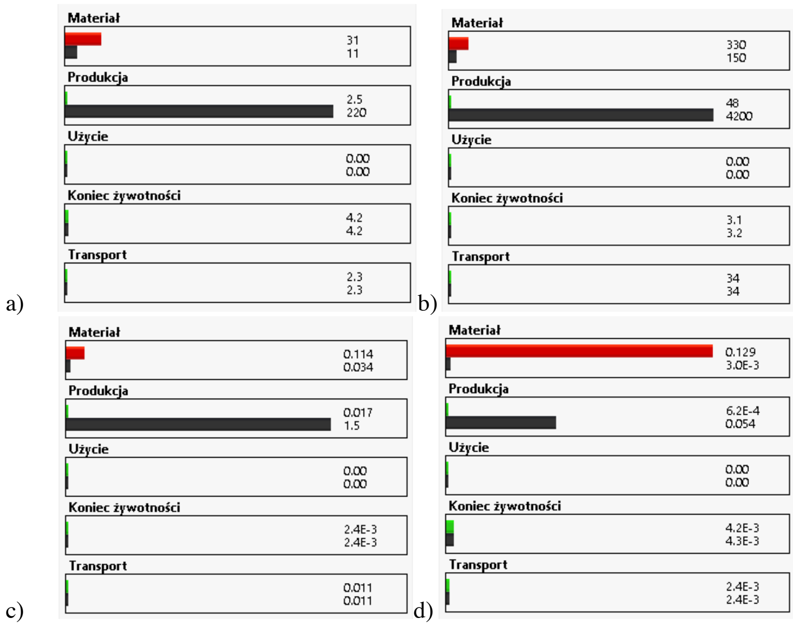


Fig. 3. Comparison of shredder rings made of S 185 structural steel (bottom columns) and X40Cr14 tool steel (top posts) in terms of a) carbon dioxide emissions, kg CO_2, b) total energy demand, MJ, c) air acidification, kg SO_2, d) water eutrophication, kg PO_4 during milling.

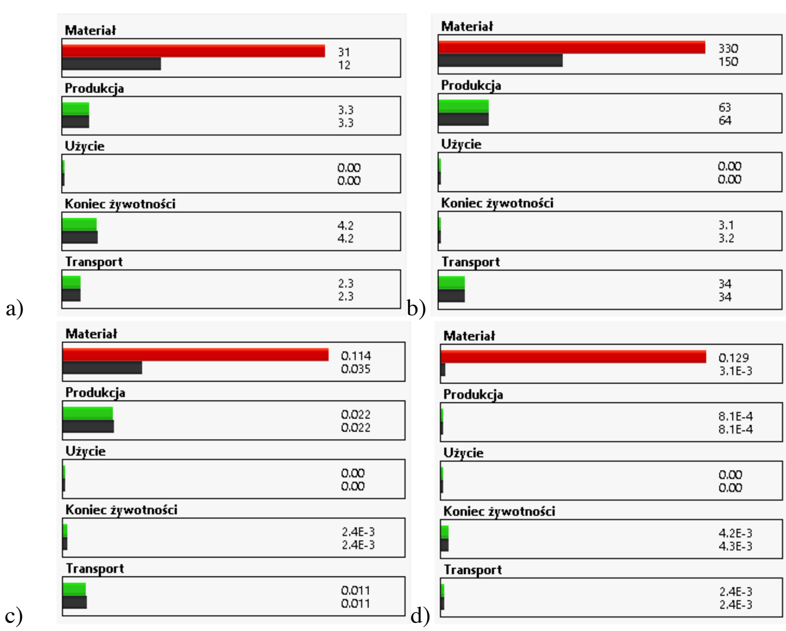


Fig. 4. Comparison of shredder rings made of S 185 structural steel (bottom posts) and X40Cr14 tool steel (top posts) in terms of a) carbon dioxide emissions, kg CO_2, b) total energy demand, MJ, c) air acidification, kg SO_2, d) water eutrophication, kg PO_4 in the turning process.

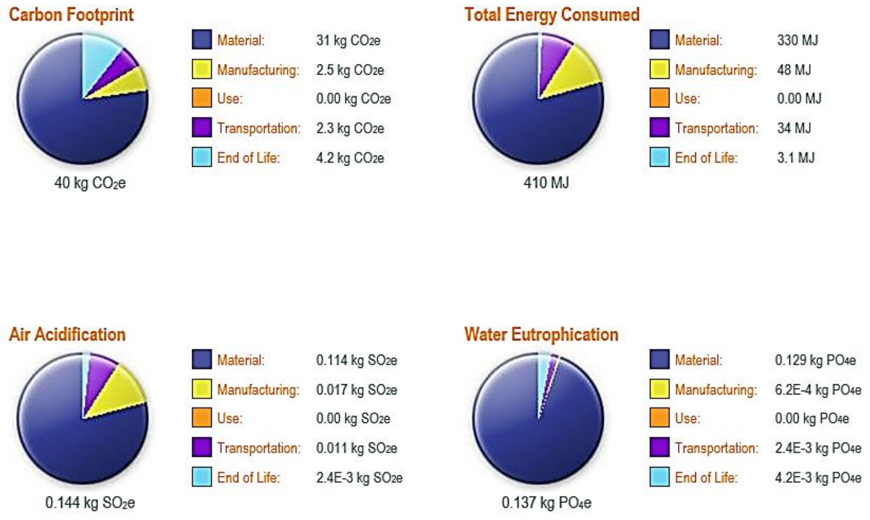


Fig. 5. Part of the final report for ten shredder rings for polymer products and waste.

Scenario 2

In the case of the second scenario, elements of the shredder's construction layout were considered, which includes a set of cutting knives with a total weight of 1.38 kg. In the first step, the process of knife processing by milling was compared for two materials: structural steel and tool steel (Fig. 6). In the second step, the process of knife processing by turning using the same materials was compared (Fig. 7). The levels of potential environmental impacts of the shredder knife set are presented in the final report (Fig. 8).

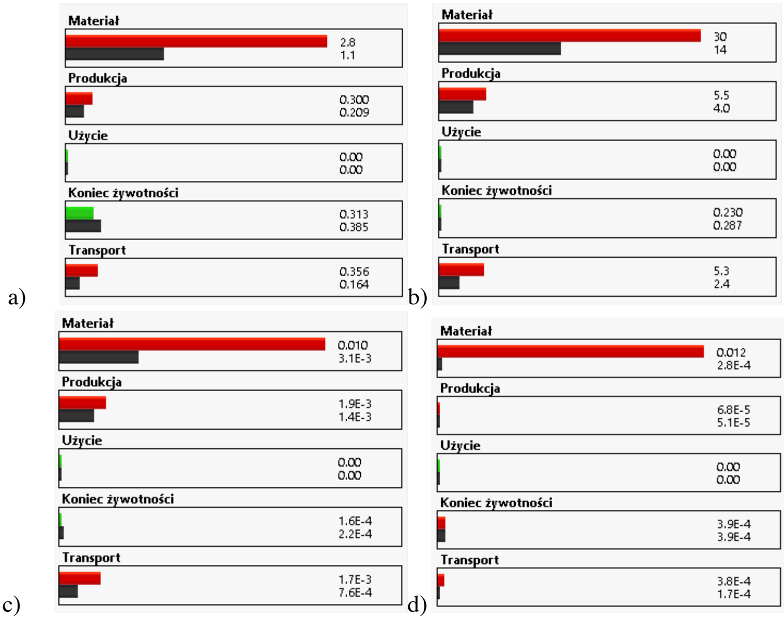


Fig. 6. Comparison of the shredder blade set made of S185 structural steel (bottom posts) and X40Cr14 tool steel (top posts) in terms of indicators a) carbon dioxide emissions, kg CO_2, b) total energy demand, MJ, c) air acidification, kg SO_2, d) water eutrophication, kg PO_4 during milling.

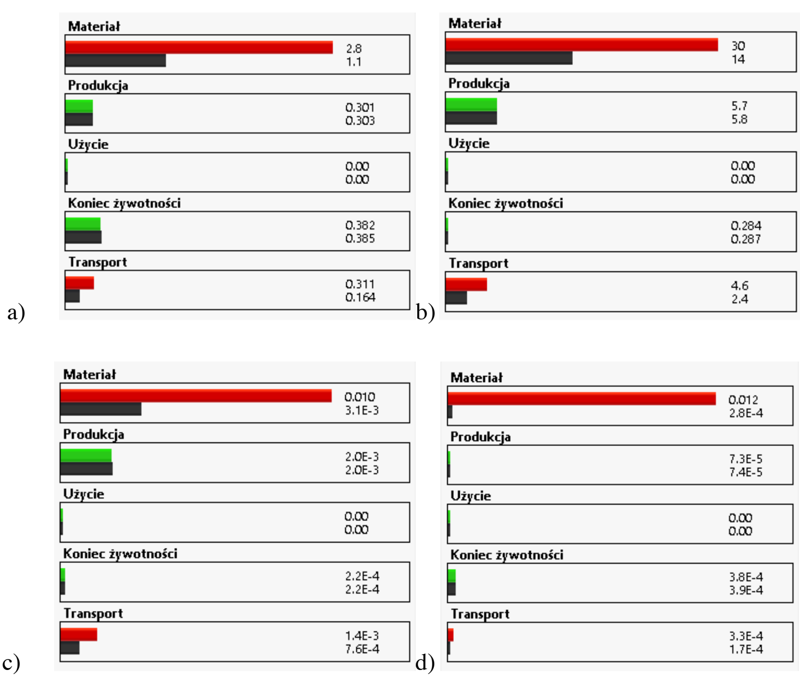


Fig. 7. Comparison of the shredder blade set made of S185 structural steel (bottom posts) and X40Cr14 tool steel (top posts) in terms of a) carbon dioxide emissions, kg CO2, b) total energy demand, MJ, c) air acidification, kg SO2, d) water eutrophication, kg PO4 in the turning process.

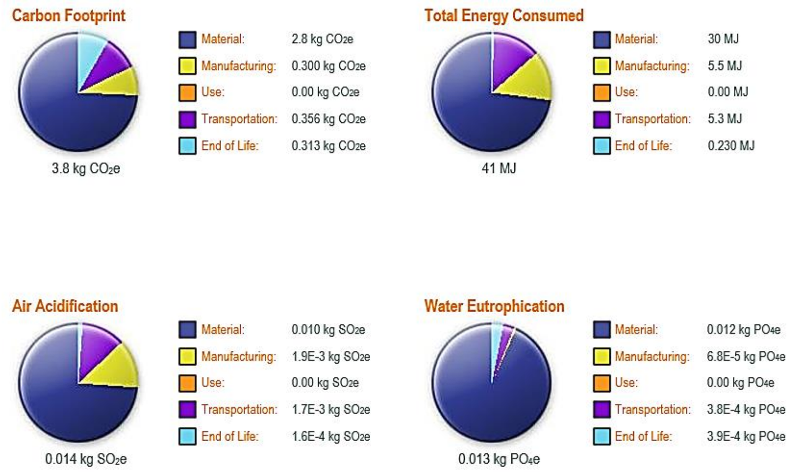


Fig. 8. Part of the final report for a set of cutting knives shredder for polymer products and waste.

Scenario 3

In the case of the third scenario, the first step was to consider elements of the shredder's structure including construction elements such as knives, rings, discs and shredder base made of structural steel milling technology. Their potential environmental impact on carbon emissions ($_{CO2}$), total energy usage (MJ), air acidification (SO_4), water eutrophication (PO_4) expressed in units of a given impact category (Fig. 9, 10) and in percentage terms (Table 1) were considered.

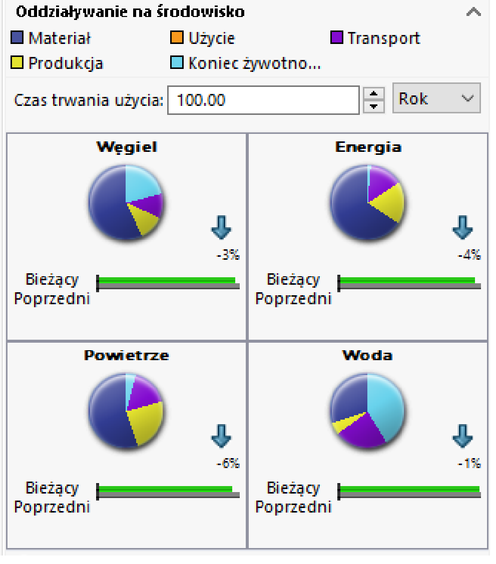
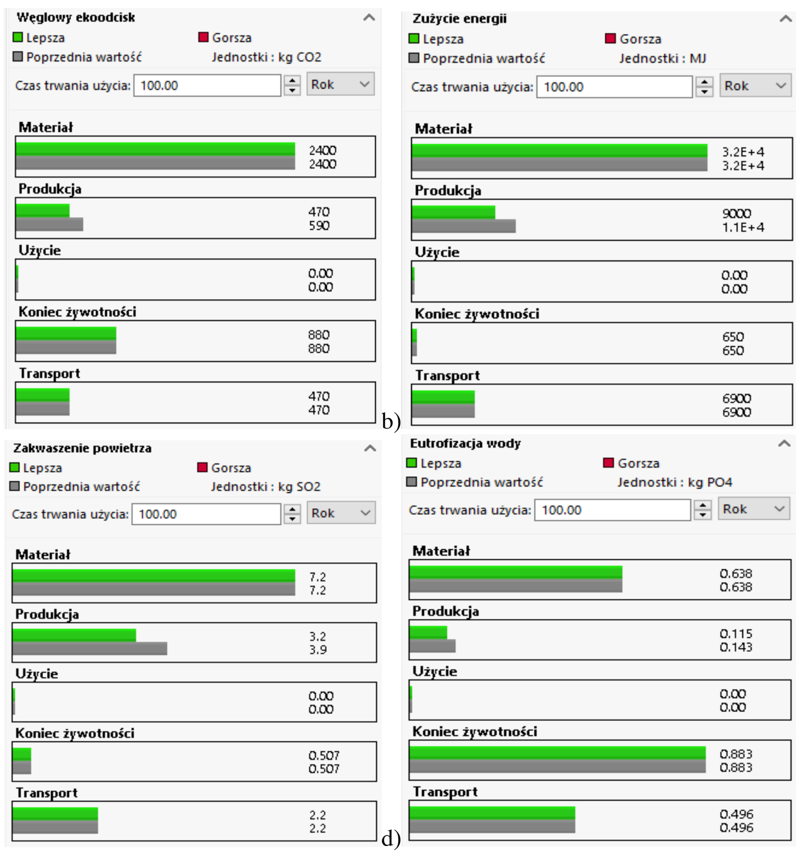


Fig. 9. Environmental impact of the shredder made of structural steel obtained during the milling process.

Table 1. Scenario 3 test results, taking into account the use of structural steel for shredder production using milling processes, %.

Areas of influence	Material	Production	Use	Transport	End of life cycle
Emissions to water	29.93%	5.41%	x	23.26%	41.41%
Emissions to air	55.02%	24.31%	x	16.78%	3.89%
Energy consumption	65.60%	18.68%	x	14.37%	1.35%
Carbon footprint	56.89%	11.22%	x	11.12%	20.77%

a)



c)

Fig. 10. Results of emissions a) carbon dioxide, kg CO_2, b) total energy demand, MJ, c) air acidification, kg SO_2 and d) water eutrophication, kg PO_4 shredder for polymeric materials made of structural steel during milling process.

In the case of the third scenario, in the second step, elements of the shredder's structure were considered, including construction elements such as knives, rings, discs and the shredder base made of tool steel milling technology. Their potential environmental impact on carbon emissions (CO_2), total energy usage (MJ), air acidification (SO_4), water eutrophication (PO_4) expressed in units of impact category (Fig. 11, 12) and in percentage terms (Table 2) were considered.

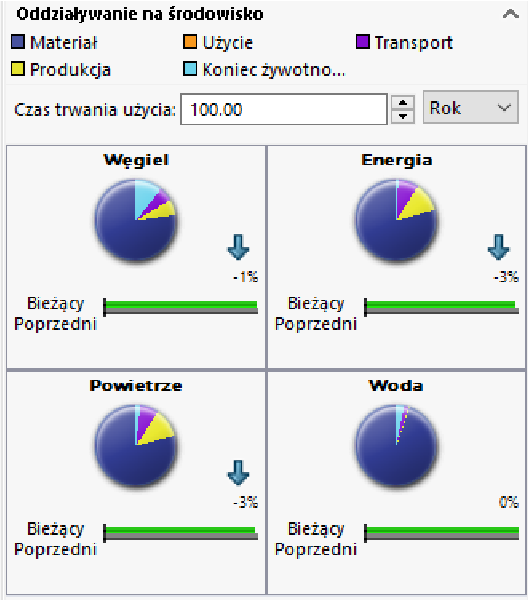


Fig. 11. Environmental impact of the tool steel shredder obtained during the milling process.

Table 2. Scenario 3 test results, taking into account the use of tool steel in milling technology, %

Areas of influence	Material	Production	Use	Transport	End of life cycle
Emissions to water	94.71%	0.45%	x	1.74%	3.10%
Emissions to air	79.22%	11.79%	x	7.30%	1.69%
Energy consumption	79.40%	11.74%	x	8.09%	0.76%
Carbon footprint	77.32%	6.40%	x	5.68%	10.61%

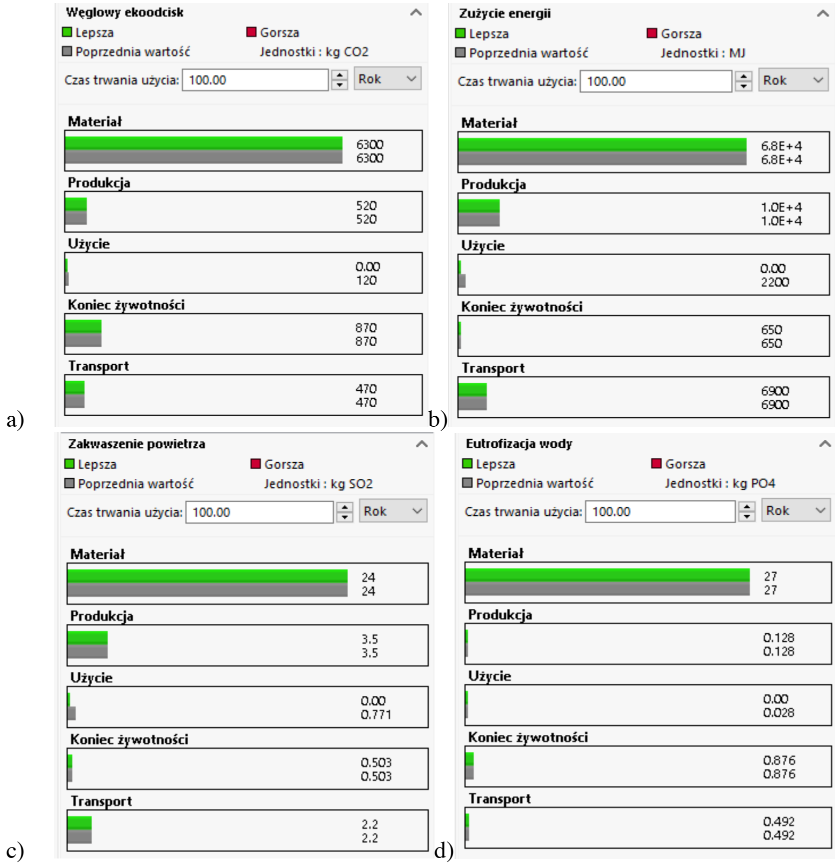


Fig. 12. Results of emissions a) carbon dioxide, kg CO_2 , b) total energy demand, MJ, c) air acidification, kg SO_2 and d) water eutrophication, kg PO_4 shredder for polymer materials made of tool steel during milling process.

5 Conclusions

The aim of the study was realized by studying and evaluating the life cycle of the polymer shredder using SolidWorks Sustainability software. Environmental analysis was conducted for impact categories such as carbon emissions, total energy usage, air acidification and water eutrophication for three scenarios (set of rings, knives and whole shredder) assuming two different raw materials and two different treatment processes. The comparison of the scenarios is focused on the assessment of electricity consumption and CO2, SO2 and PO4 emissions. For these parameters, a functional unit defined as 100 operating hours was set as a reference.

For the assessment of the carbon footprint emissions, comparable environmental damage was observed when using structural steel (31 kg CO2eq) both during milling and turning operations (scenario 1). The milling process of structural steel at the production stage was much more energy-intensive than the turning process. Throughout the entire period of assessment of environmental damage caused by air acidification by production, use, handling and transport of shredder rings, a greater negative impact of the milling process was noted. For the assessment of water eutrophication, a higher level of emissions was noted for structural steel (0.054 PO4eq) than for tool steel (0.00062 PO4eq) during the milling process.

During the assessment of the environmental emissions of the cutting knife set (scenario 2), which is a key element of the examined object, the highest levels of CO2 (30 kg CO2eq) were recorded for the materials used and the compared machining processes. Energy extraction and consumption in the adopted processes is an important ecological element in the whole life cycle of the shredders. In the production process of cutting knives, the greatest environmental impact is caused by energy consumption (30 MJ) for tool steel and (14 MJ) for structural steel for both milling and turning operations.

In light of the above, a comparison of two types of materials for the milling process with respect to all elements of the shredder structure, i.e. base, knives, rings and disks (scenario 3), was assumed to be significant and necessary for the environmental assessment. On this basis, it can be concluded that the use of tool steel is more harmful to the water environment than structural steel. In addition, the research carried out has shown that the second factor determining the impact categories is the energy consumption at the stage of selection of raw material and production process. As it was shown, the highest energy consumption is characterized by the selection of tool steel.

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