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Simulation of Kinematic and Strength Analysis of a Conical Shredder

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Abstract. The paper presents the opportunities for the adjustment of operating parameters and constructional parameters of shredders for polymer materials using CAD/CAE tools. The object of research is a conical shredder developed on the basis of a patent. For studies SolidWorks application with simulation and motion option has been used.

1 Introduction

Grinders belong to the group of machines used in many branches of industry both in production and recycling [1-4]. The problem to be solved in the shredder design is to reduce energy demand for shredding the unit of mass, increase process efficiency and improve the quality of shredding product [5-8]. Shredders are used for shredding a wide range of materials; polymers [9], biological materials [10], in the processing of brittle materials [11], in the process of wastewater treatment by means of coagulation [12], in wood chipping [13,14]. In the field of processing of polymeric materials, achieving the expected dimensions is important for further processing [15-18].
The improvement of the grinding parameters is possible thanks to the implementation of modern tools, such as computer-aided design systems CAD/CAE [19]. These methods also occurs in the field of recycling [20], design of pelletizing machines [21,22,23] and generally in engineering practice [24,25]. CAD/CAE methods can provide a number of advantages, such as: reduced time of pro-designing new solutions, reduced costs of prototype production by creating a virtual model and detailed research of mechanisms performed in a computer standard. For a long time the methods have been used successfully in the field of strength simulations [26,27], and in the field of vehicle adhesion analysis [28]. Computer design tools are also used in medical engineering [29-35]. Computer-aided design tools also include Artificial Intelligence (AI) methods [36]. By means of process analysis, computer simulations and experiment, it is possible to estimate with great approximation - when changing the structural features and relations between these features - for a selected group of machines, the range of changes in the functional characteristics under operating conditions. Industrial robots play an important role in the search for optimization of machine operation [37,38]. In the design-construction process, in which the

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concept of a new machine is fixed on an information carrier, it is prepared to create a constructional dock. Modern forms of recording made in 2D and 3D standard are the basis for the construction of mechanism models and assemblies. In the CAD/CAE application group SolidWorks is one of the programs. It has several sub-applications used for strength and kinematic simulations.

2 Research object - conical shredder

Due to the variety of sizes, shapes and properties of the mechanic materials to be shredded, various shredder designs are used. Complex disintegration processes take place in the working systems. The process is determined by the geometric characteristics (shape, size, porosity of the shredded elements and properties which, in consequence, differ significantly from those of quasi-static and intermediate loads in terms of dynamic separation. The complexity of the issues also concerns the influence of the design features of the shredding (thickening) elements and a number of operating parameters on the unit energy consumption and performance. Most often, the essence of the shredders is to use the method of cutting, shearing and hammering the material in order to disintegrate it. The exceeding of permissible stresses in the material causes their separation - disintegration. The appropriate method of separation guarantees low power consumption during shredding and ensures the correctness of the shredding process while maintaining the required degree of shredding. A conical shredder according to the national patent was proposed for testing [39]. The essence of the cone shredder consists in the fact that the working unit consists of 2 sets of rings (external - fixed and internal - movable) with exchangeable knives embedded on their circumferences (fig.1).
The design of the conical shredder has been prepared in the SolidWorks application, with mapping of individual parts, subassemblies and assemblies (Fig.2). The shaft together with a set of rings, knives and lower disc performs a rotary motion. The set of outer rings together with knives is fixed and the inner diameters of these rings decrease from top to bottom, while maintaining a constant outer diameter.

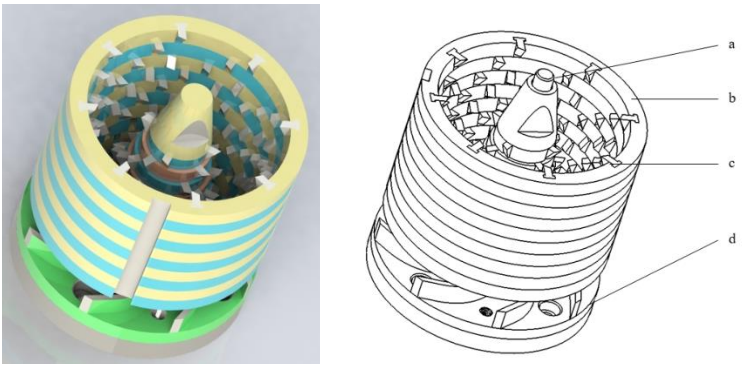

Fig. 1. General view of the shredder for polymers; a) movable shaft with set of rings and knives, b) set of fixed rings with knives, c) one of many replaceable knives, d) bottom shield connected to the movable shaft and equipped with overturn elements.

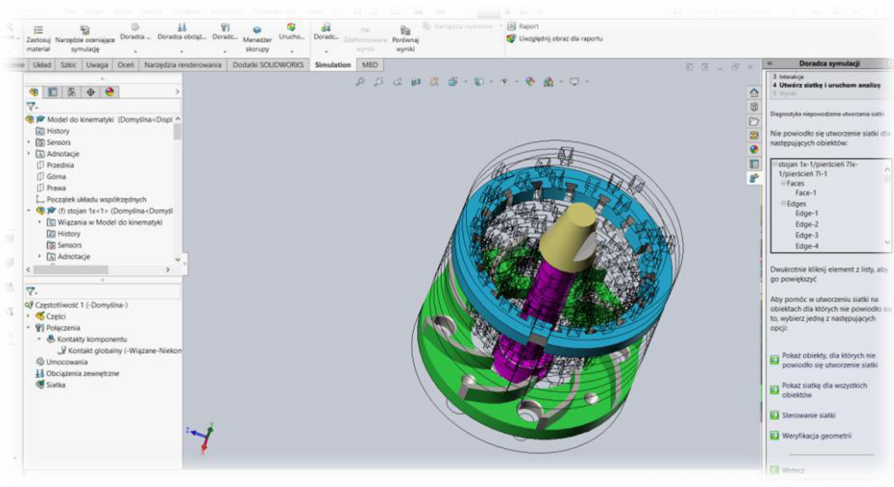

Fig. 2. Shredder design view in SolidWorks application.

3 Shredding kinematics simulation

The following types of tests can be carried out in SolidWorks application: static tests (stress simulations), frequency analysis, buckling tests, thermal tests, design tests, non-linear tests, linear dynamic tests, drop test, fatigue tests, pressure vessel design tests, simplification tests [40, 41].

Static tests enable calculations of displacement, reaction force, deformation, stress and safety factor distribution. The material is destroyed in places where the stresses exceed the elasticity level. Calculations of the safety factor are based on the damage criterion. Static tests help to avoid damage due to high stresses. A safety factor less than 1 means the destruction of the material. Large safety factors in a given area indicate low stresses and the possibility of removing a certain amount of material from the area. Frequency analysis helps to avoid damage due to overstress caused by resonance. It also provides the information needed to solve dynamic reaction problems. An excessive object reaction occurs if the body is subjected to a dynamic load acting at one of the natural frequencies. Buckling tests refer to sudden, large displacement caused by axial loads. Slim structures subjected to axial loads can be damaged by buckling at load levels lower than those necessary to cause material damage. Buckling can occur for different mods under different load levels. In many cases, only the lowest buckling load is interesting. Buckling tests help to avoid damage due to buckling.

Thermal testing provides the ability to calculate temperature, temperature gradients and heat flow based on conditions of heat generation, conduction, convection and radiation. Thermal studies help to avoid undesirable thermal conditions such as overheating and melting. The optimization design studies automate the process of finding the optimal design based on a geometric model. The software is equipped with a technology for quick trend detection and identification of the optimal solution with the smallest number of passes. Non-linear tests are used when there are erroneous results in linear tests, because the assumptions on which they are based are not fulfilled. Non-linear analysis can be used to solve non-linearity problems caused by material behavior, large displacements and contact conditions. Static as well as dynamic tests can be defined.

Drop test tests estimate the effects of dropping a part or folding on a rigid or flexible floor. The drop test can be used to simulate a collision of the model with a rigid or flexible planar

surface. Fatigue tests are used for repeated loading, even when the induced stresses are significantly less than the permissible stress limits. Structural linear or non-linear tests do not predict fatigue failure. If the assumptions of the analysis are met and the calculated extra stresses are within acceptable limits, they assume that the design is safe in the given environment no matter how many times the particular load is applied. Fatigue tests estimate the proportion of service life that has elapsed based on fatigue cases and S-N curves.
Pressure vessel design tests combine the results of static tests using the required factors. Each static test has a different set of loads that generate the corresponding results. The loads can be fixed loads, moving loads (approximate static loads), thermal loads, seismic loads, etc. Testing The pressure vessel design combines the static test results in an algebraic way using a linear or square root of the sum of squares (SRSS).
The SolidWorks motion module offers an interesting set of tools, especially at the stage of model construction (assembly) and initial verification, e.g. collision checking during movement of individual elements. With the attached option of motion analysis we can carry out four types of analysis: a) displacement, velocity, acceleration, b) forces, c) momentum, energy, power and d) other quantities (fig. 3).

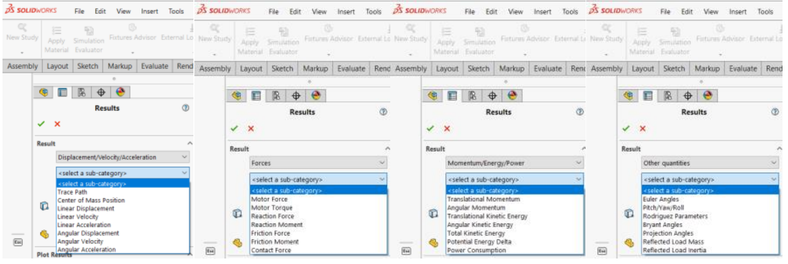

Fig. 3. Simulation possibilities in the range of motion in SolidWorks; a) displacement, velocity, acceleration, b) forces, c) momentum, energy, power and d) other quantities.

Simulation tests of the cone shredder in SolidWorks motion application have been carried out at preset speeds of 100, 150 and 200 rpm (Fig. 4). Even though the results do not bring any revealing conclusions, they can be used for a full kinematic analysis for a wide range of rotational speeds and the way of starting the shredder itself.

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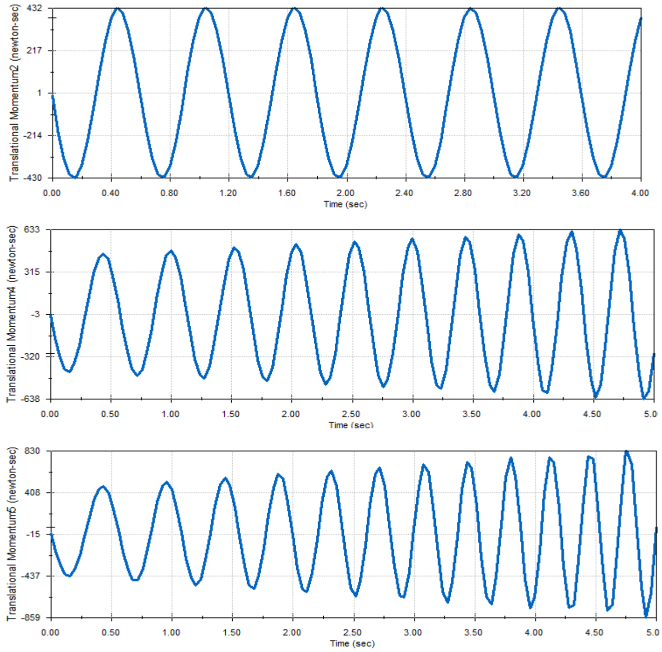

Fig. 4. Results of momentum simulation for speeds 100, 150 and 200 rpm of a conical shredder with moving rotor.

After defining the speed value, the speed was determined for the speed. Additionally, it was possible to verify the linear velocity ranges for individual cases of a tooth on a moving disc - a tooth on a fixed disc (Fig. 5,6,7).

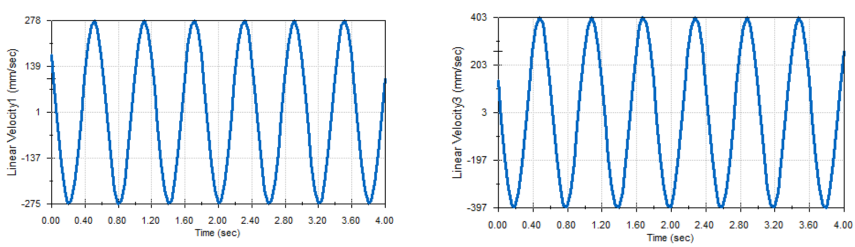

Fig. 5. Linear speed ranges for 100 RPM between fixed and movable tooth on the first (a) and fifth ring (b).

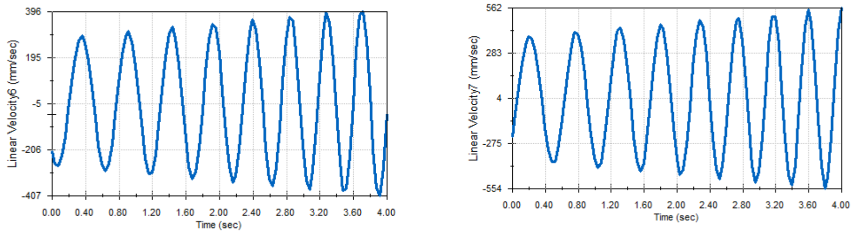

Fig. 6. Linear speed ranges for 150 RPM between fixed and movable tooth on the first (a) and fifth ring (b).

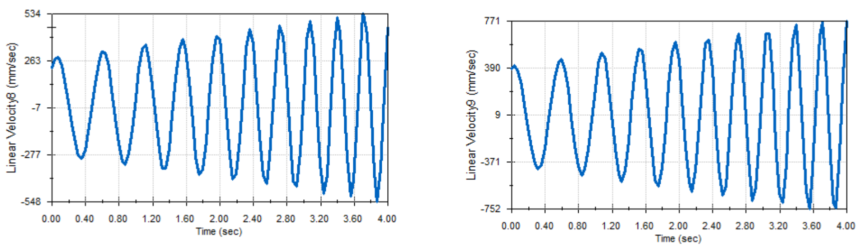

Fig. 7. Linear speed ranges for 200 RPM between fixed and movable tooth on the first (a) and fifth ring (b).

On the basis of the above results of speed changes between the movable and fixed tooth we can observe minimum and maximum speed ranges, respectively 278-403, 396-562, 534-771 rpm. Additionally, linear acceleration was verified for the same speeds (Fig. 8,9,10). Orientation of one coordinate system relative to another is defined by a sequence of three successive rotations. Yaw, pitch, and roll define one such space-fixed rotation sequence. There are multiple ways to define this sequence. Yaw, pitch, and roll angles in Motion Analysis results are the sequence of Z-, negative Y-, and X-axis rotation angles measured about the rotating coordinate system, relative to the global coordinate system. Yaw - the first angle of rotation in the yaw, pitch, and roll sequence. Yaw measures the rotation about the Z-axis of the rotating coordinate system relative to the global coordinate system.Pitch - the second angle of rotation in the yaw, pitch, and roll sequence. Pitch measures the rotation about the negative Y-axis of the rotating coordinate system relative to the global coordinate system after the yaw rotation has been applied.Roll - the third angle of rotation in the yaw, pitch, and roll sequence. Roll measures the rotation about the X-axis of the rotating coordinate system relative to the global coordinate system after the yaw and pitch rotations have been applied.

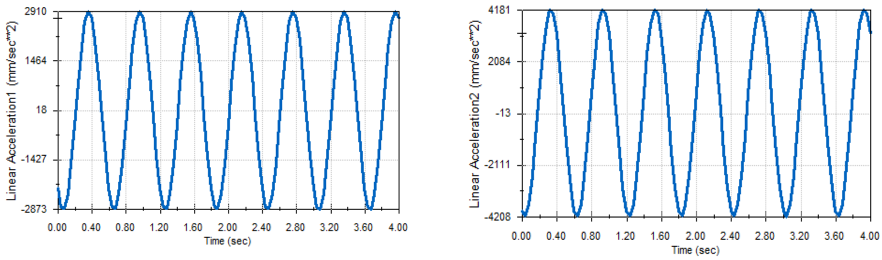

Fig. 8. Linear acceleration ranges for 100 RPM between the fixed and movable tooth on the first (a) and fifth ring (b).

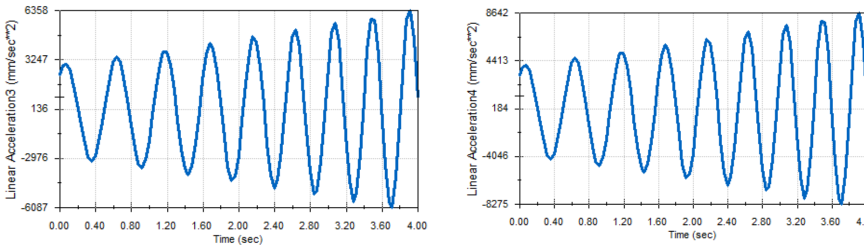

Fig. 9. Linear acceleration ranges for 150 RPM between the fixed and movable tooth on the first (a) and fifth ring (b).

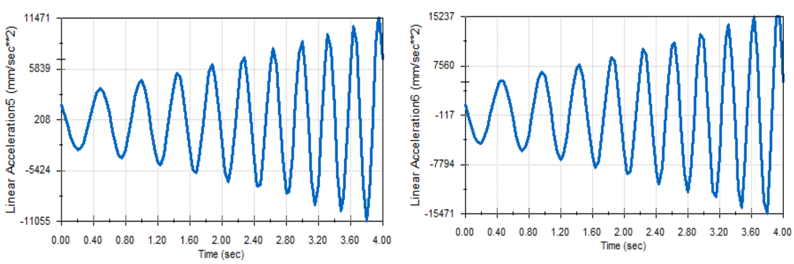

Fig. 10. Ranges of linear acceleration for 200 RPM between the fixed and movable tooth on the first (a) and fifth ring (b).

On the basis of the above studies, the linear acceleration ranges for 100, 150 and 200 rpm were estimated; they are 2.9 - 4.2, 6.35 - 8.6 and 11.47 - 15.23 m/s2. Thanks to the conducted research, it was possible to estimate energy expenditure during idling for particular rotational speeds (Fig. 11).

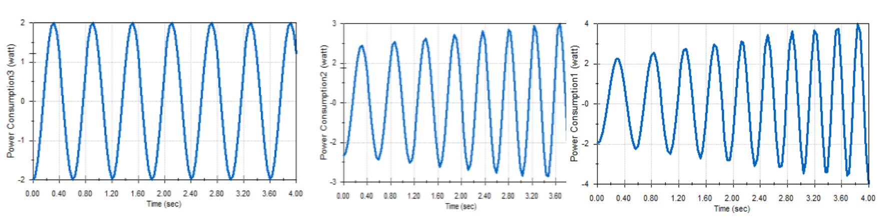

Fig. 11. Indicative ranges of energy demand for idling operation for 100, 150 and 200 rpm.

Additionally, integrated simulations for Euler angles and projection angles and horizontal deviation were performed (Fig. 12). As mentioned earlier, they are rather comparative and quite idealised, but at the stage of establishing initial kinematic relations they provide a lot of information in terms of selection of constructional features and operational parameters.

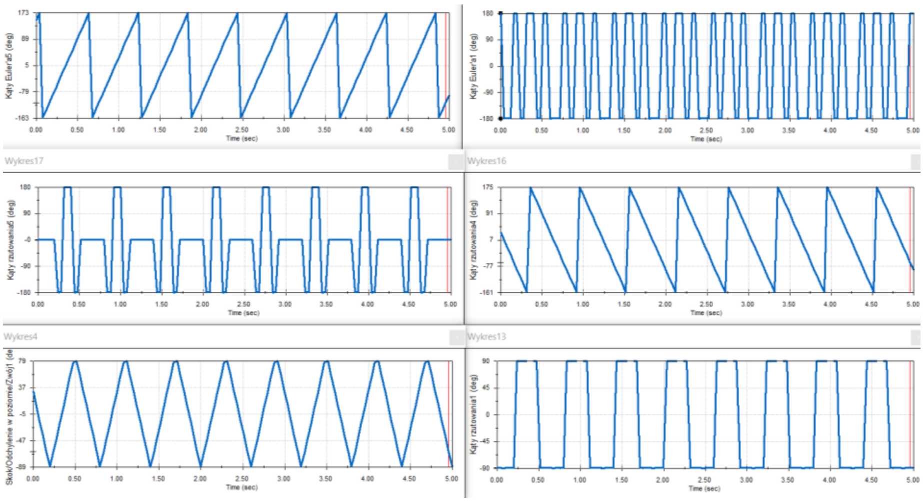

Fig. 12. Euler angle variation ranges for different speeds: 100, 150, 200 rpm. projection angles for 150 and 200 rpm and horizontal jump/pitch for 150 rpm.

Orientation of one coordinate system relative to another is defined by a sequence of three successive rotations. The three Euler angles define one such body-fixed rotation sequence. The three Euler angles, Ψ, Θ, and Φ in Motion Analysis results are the sequence of Z-, X-, and Z-axis rotation angles measured about the body of the rotating coordinate system. Psi - the first angle of rotation in the Euler angle rotation sequence. Ψ measures the rotation about the Z-axis of the rotating coordinate system. Theta - the second angle of rotation in the Euler angle rotation sequence. Θ measures the rotation about the X-axis of the rotating coordinate system after the Ψ rotation has been applied. Phi - the third angle of rotation in the Euler angle rotation sequence. Φ measures the rotation about the Z-axis of the rotating coordinate system after the Ψ and Θ rotations have been applied.
An additional benefit is the analysis of the position of the teeth on the moving disc in relation to the teeth of the fixed disc, as can be seen in Figures 13 and 14.

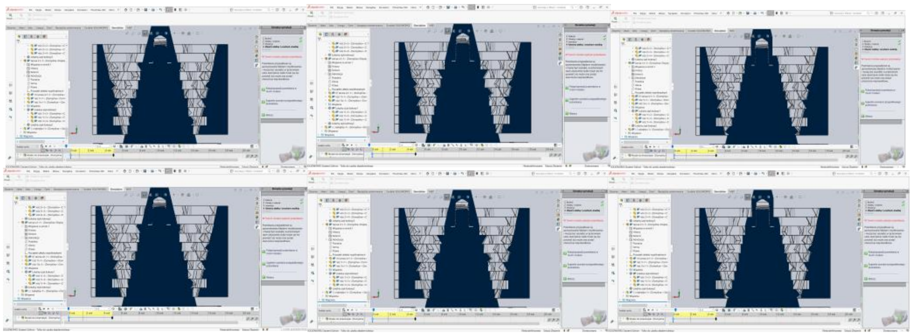

Fig. 13. View of the shredder chamber cross-section in 10-degree steps (from 30° to 80°).

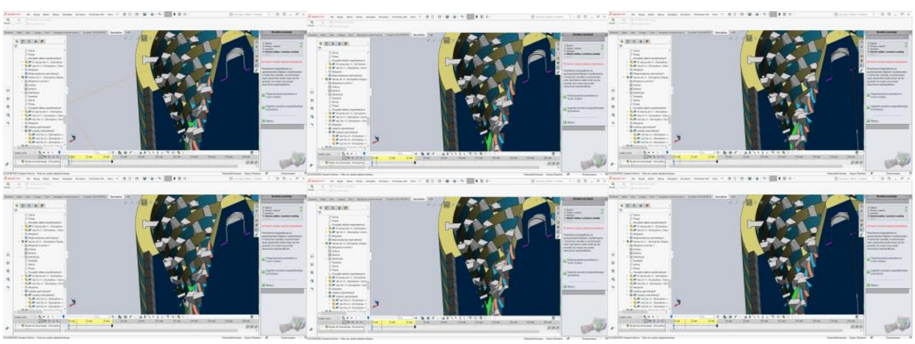

Fig. 14. Spatial view of the fixed and movable discs with teeth in the following 10 degree steps (from 30° to 80°).

4 Testing of strength properties

Strength tests were conducted for three samples of PP, PE, PVC. Geometrical features of a third row disc subjected to rotational movement and generating 100 Nm of torque and a 50 mm diameter tubular element (polymer) were used. The research was also aimed at determining the approximate stress range and the method of stress concentration (Fig. 15).

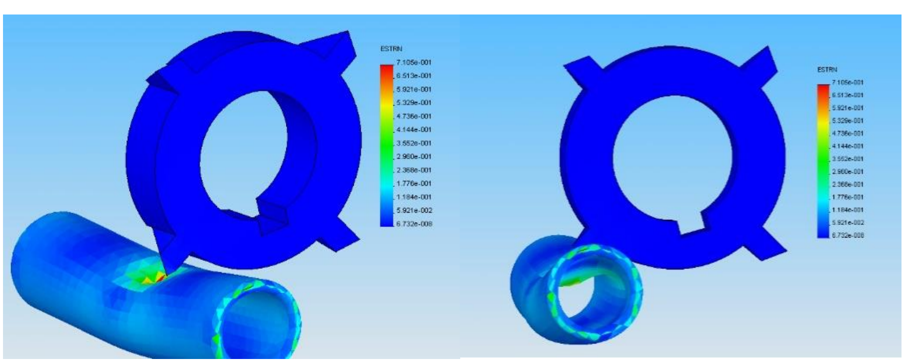

Fig. 15. Strength simulation using a blade with a knife and a tube section polymer sample.

On the basis of the analyses carried out, approximate ranges of sample deformation in the temperature range from – 20° to + 20°C were estimated. The results of the simulation are presented in Fig. 16–18.

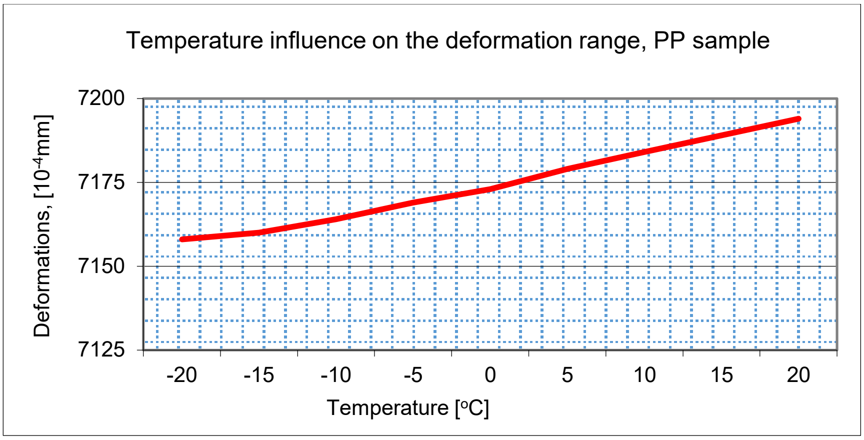

Fig. 16. Results of simulation studies on the influence of temperature on the deformation level of the comminuted PP sample.

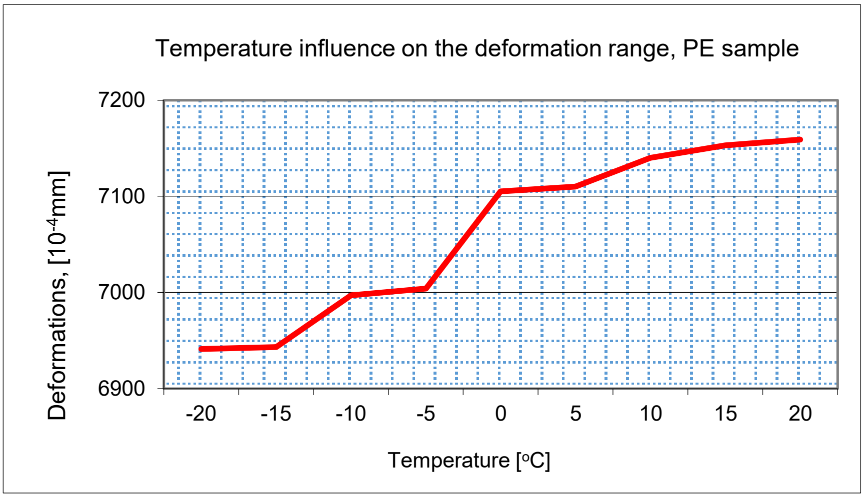

Fig. 17. Results of simulation studies on the influence of temperature on the deformation level of the comminuted PE sample.

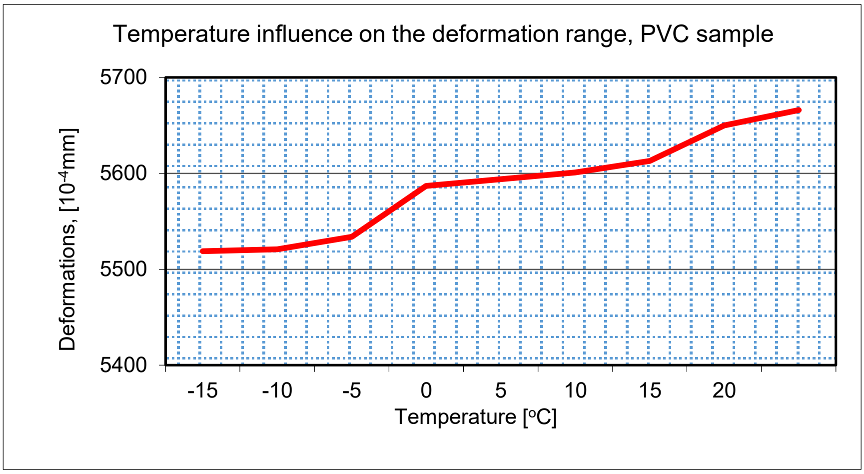

Fig. 18. Results of simulation studies on the influence of temperature on the deformation level of the comminuted PVC sample.

5 Summary and conclusions

The purpose of the strength simulations and motion analysis was to better understand and describe the impact of the design features of the cone shredder disintegration unit on the performance and operational characteristics. The obtained results of the simulation, although they indicate ranges of variability of particular characteristics, should be analyzed in detail before undertaking significant structural changes. The results of these analyses allow to indicate the range of "usability" variables of the shredder construction and their indicators. The functions of the research objects, supported by the substantial knowledge, allow for a qualitative description - in the direction of building mathematical-physical models. Thanks to that, in shredded objects it is possible to analyze stress distribution using MES, as well as to create a unified form of recording and collecting data about the structure. Shredder constructions are subject to continuous development and innovations are aimed at achieving better and better performance characteristics. The conical shredder is an example. The fact that about 80% of the total investment in the development of innovations is planned in the area of computer model research is in support of this kind of work in the use of CAD/CAE tools. The remaining 20% is the area for the development of a prototype version. The need for such research becomes even more apparent in the area of design and shredder research, where planning an experiment with computer-aided design is one of the first stages.

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