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Use of the Finite Element Method in the Prediction of Stresses and Strains in Roller Press Frames

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Abstract. In the article the design solutions for the roller presses have been characterized. On this basis, several roller press models were selected, their CAD models were prepared and then the loads have been put on the roller press frames and other components of the presses. The results of a stress and strain analyses have been done using the finite element method. A comparison of individual solutions are presented. On the basis of the analysis performed, the construction of the considered object are rated and solutions aimed at improving the existing solutions are presented.

1 Introduction

An important operational aspect of roller presses designed for the briquetting of fine-grained materials (Fig. 1), as in most machines employing a similar principle of operation (rolling machines, roller mills, HPGR crushers), is their required high structural rigidity [1-6]. It is a primary feature of every compaction machine and it has an effect on the correct production of briquettes, especially their proper compaction degree [7,8].

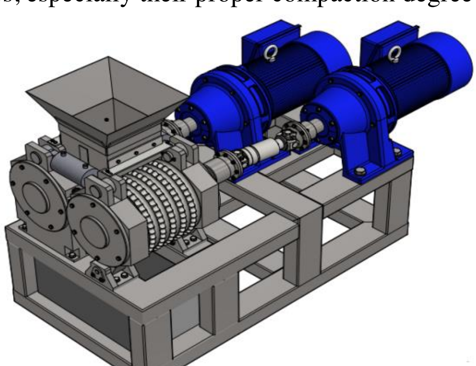

Fig. 1. The view of a roller press designed for briquetting lignite.

Insufficient rigidity of roller briquetting machines widens the gap between the rollers which implies the decrease of the unit pressure in the moulding cavity [9,10]. This has been proved by both laboratory and industrial scale experiments as well as simulation tests [11]. An increase of the gap from 1 mm to 2 mm in a roller press with 450 mm diameter rollers results in a reduction of pressure by about 25%. While briquetting fine-grained materials in roller presses, the compaction implies forces which push apart the moulding rollers and which often reach as much as 25 MN [12]. So the basic function of frames used in briquetting machines is to ensure a properly rigid spatial structure which will deform only to a minimum degree as a result of the forces occurring during the consolidation of materials so as to ensure that it does not cause excessive disturbances in the briquetting process [13,14,15]. It is quite difficult to calculate deformations of briquetting machine frames by means of classical computational methods especially since these are spatial designs which are often statically indeterminable [4,10]. It is, however, possible to use a proper engineering software for this purpose, which is a purpose of this article.

2 General Review of Briquetting Machine Frame Designs

Frames of briquetting roller machines can be designed in many different ways, depending on the size of presses, their efficiency and purpose. The basic part of frames of briquetting machines are moulding roller cages. These are elements in which operating rollers with bearing housings are placed. The most popular solutions are roller cages built of two independent frames which are connected to each other [16].Other frequently used solutions include closed-type structures with a monolithic frame and solutions with a split frame [17]. The monolithic frames are used mostly in roller presses in which moulding rollers operate outside the roller cage [18]. Such solution allows to easily install and remove the consolidating rings [19]. Solutions of this type are used, among others, in B220B, B400B and BH400CH briquetting machines made by K.R. Komarek Inc. Contemporary structures of roller presses more and more often use split frames. Such solution significantly simplifies and streamlines the process of replacing the moulding rings and it also allows to save time necessary to carry out this process [17]. Cages with a split frame are built of two frames. Each of them consists of two longitudinal sections and two clamps interconnected with pin connections [19]. Among others, Köppern uses solutions of this type in its briquetting machines. Among various designs of roller briquetting machines, there are also solutions with a frameless design of the moulding roller cage [8].Such solutions have been used so far in high-efficiency roller presses [19]. In such case, load-bearing elements are moulding roller bearing housings which are coupled by means of hydraulic actuators.
Structures of the briquetting machine frames mainly convey loads from the drive system and loads generated on the briquetting machine moulding cavities during the fine-grained material consolidation process. The volume of these loads and their distribution have a major effect on the briquetting process and it is important to know them in order to ensure that the process is correct [20].

3 Methodology of Research

In order to determine actual stress levels and deformations of operating cages of roller briquetting cages, relevant simulations based on the finite element method were performed. All analyses were made in the Femap. Roller presses with varying frame designs were used for the simulations. The available PW280 model press was used and the press models B220B, B400B, B400CH, DH300, DH400, DH450 and DH500 were replicated based on the information provided by the manufacturer. The PW280 press is a lightweight machine with an open working roller cage. In this solution, loads coming from the working system are conveyed through bearing housings and supports. The PW280 press is equipped with a 5.5 kW power motor and the 309L3 planetary gearbox which drives 280 mm diameter and 70 mm wide rollers with a speed of 8 RPM, and a standard gap between both rollers 1 mm. The torque is transferred to one of the rollers and then distributed by means of an open toothed gear. Figure 2 presents the PW280 briquetting machine with its overall dimensions.

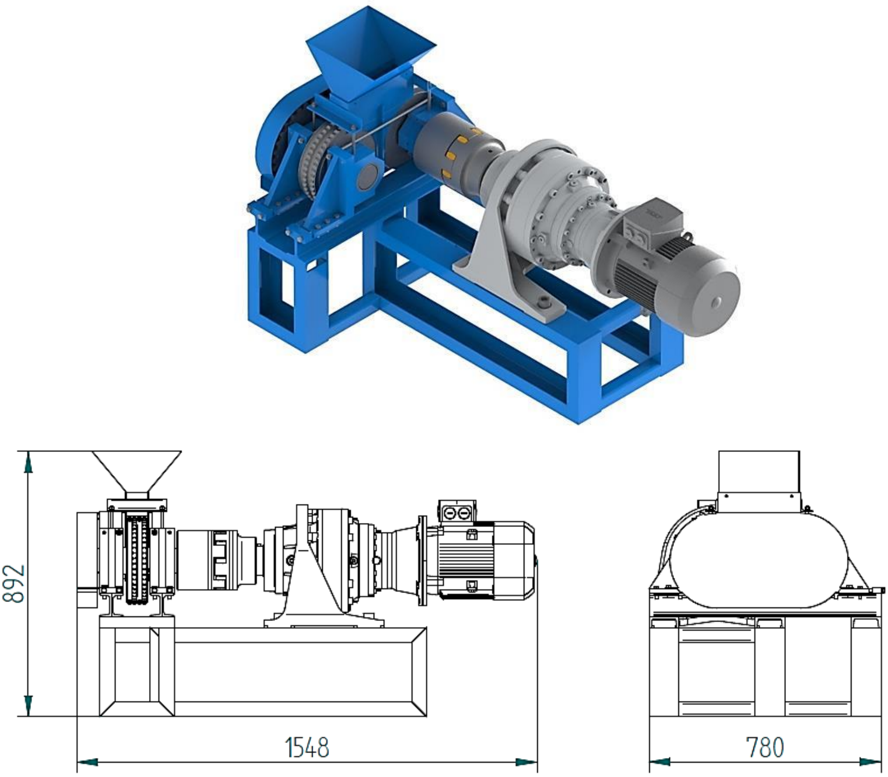

Fig. 2. Diagram and overall dimensions of the PW280 roller press.

In order to properly perform the FEM analysis, the existing PW280 press model was simplified in a number of ways. The installed moulding rolls with saddle-shaped moulding cavities were replaced with plain rollers, slide bearings were replaced with bushings and the clutch was replaced with a step-type bushing. These simplifications were done to facilitate the discretization of these parts into finite elements. Also, less important parts which would not have any effect on the final results of the analysis were removed from the model. Then, bolted connections present in the briquetting machine structure were replaced with welded connections. The "glued" type connection, available in the Femap software, was used for this purpose (Fig. 3).

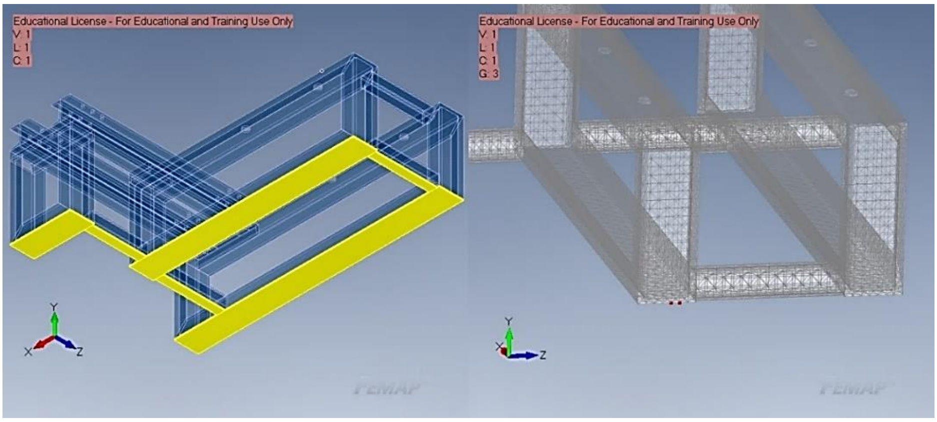

Fig. 3. The mates given in the model.

The mates between particular components of the PW280 roller press were selected depending on the type of their interaction in an actual machine. To run a simulation, a material conforming to the press documentation, i.e. the S275 steel was used for the frame elements. In the calculations 3D 4-node tetrahedral mesh were used in all cases being considered (Fig. 4).

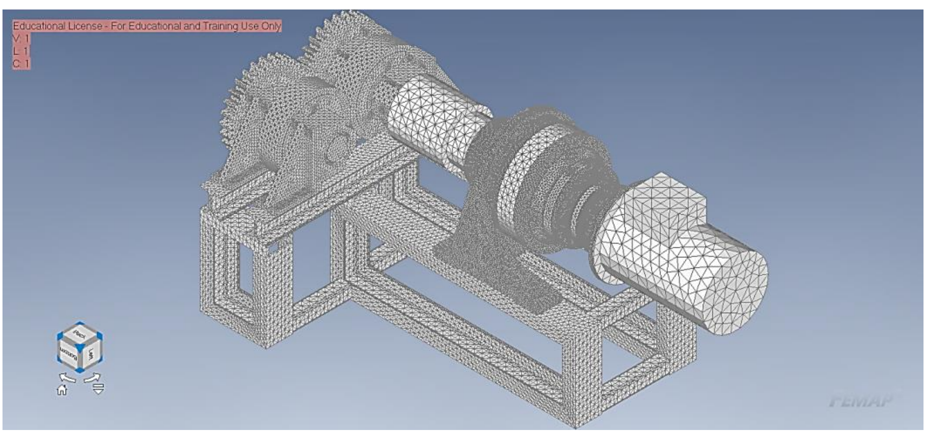

Fig. 4. Model of the PW280 press after applying the finite element mesh.

Their dimensions were adjusted to the shapes and sizes of individual parts of 3D models. In the prepared computational models, constant load of a total value of 100 kN was applied along a curve placed on the cylindrical surface of the working rollers in a direction parallel to a straight line going through the axes of both rollers (Fig. 5). The load was oriented towards the center of the rollers. A load was also applied in a toothed gear to teeth being engaged respectively with a peripheral component equal to 18.714 kN and the radial component equal to 6.793 kN. The design was also loaded with a torsional moment equal to 2.62 kNm, calculated based on the briquetting machine drive power, and applied in half to each of the rollers (Fig. 6). Gravitational forces have also been taken into account. Designs of the B220B, B400B, B400CH, DH300, DH400, DH450 and DH500 briquetting machines significantly differ from the design of the PW280 press. These are presses with two moulding rollers with a closed frame design. A 3D model of each press was replicated based on assembly drawings provided on the manufacturer's website [18].

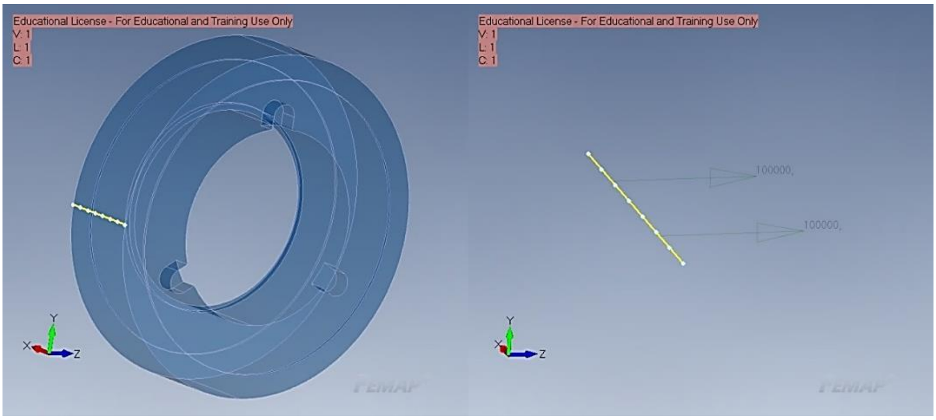

Fig. 5. The load applied to the forming roll.

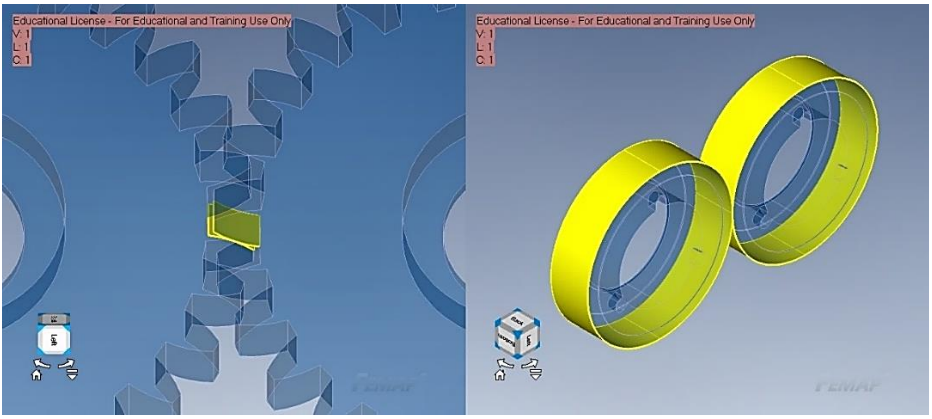

Fig. 6. Location of places where loads are applied on gear wheels and working rollers.

Several simplifications were implemented in the body models of the briquetting machines; among others, the drive system, roller pressure system and material container were abandoned. It was also decided to use plain rollers, replace bearings with bushings, simplify shapes of particular parts to make them as basic as possible and omit less important components. All bolted connections were replaced with welded connections. Similarly to the design of the PW280 briquetting machine, 4-node finite elements were used to apply the mesh of finite elements of other briquetting machines. It was assumed that the moulding roller cages were made of the S355 steel. In order to situate models in space and prevent their uncontrolled movement, three translational degrees of freedom were deactivated in four extreme holes of the lower part of the frame in all tested designs. The extreme lower surface of the frame was also prevented from moving vertically downwards. In the prepared models, the load was applied similarly as in case of the PW280 press, i.e. along the section placed on the surface of the working rollers. The value of the applied torsional moment was determined based on the motor power and the speed of the moulding rollers, with the occurring power losses being taken into account. In the solutions being tested, the drive system consists of a roller transmission having two output rollers and distributing the torque onto two moulding rollers, which is why the loads coming from the meshing of the gear synchronising rotations of the rollers are not taken into account. Load from gravitational forces has also been taken into account in the analysis. Table 1 presents key information about the analysed roller press designs.

Table 1. Applied load of the analysed briquetting press models [18].

Briquettingmachine	Constant load on working roller [kN]	Torsional moment on working roller [kNm]	Assumed rotational speed of moulding rollers [RPM]
B220B	311	3.866	15
B400B	1067	28.994	10
B400CH	980	71.905	10
DH300	670	14.432	15
DH400	1334	28.994	10
DH450	1780	54.122	8
DH500	2936	89.881	8

4 Research results and their analysis

The analysis of the PW280 briquetting machine design mainly focused on the press frame and the bearing supports. The briquetting machine frame was a welded frame, made of 80 and 100 mm wide channel sections and 50x50x4 mm profiles. The distribution of stresses and complete displacements of the tested elements are presented on Figures 7and8. Stresses on all figures in this chapter are expressed in MPa and displacements are expressed in mm.

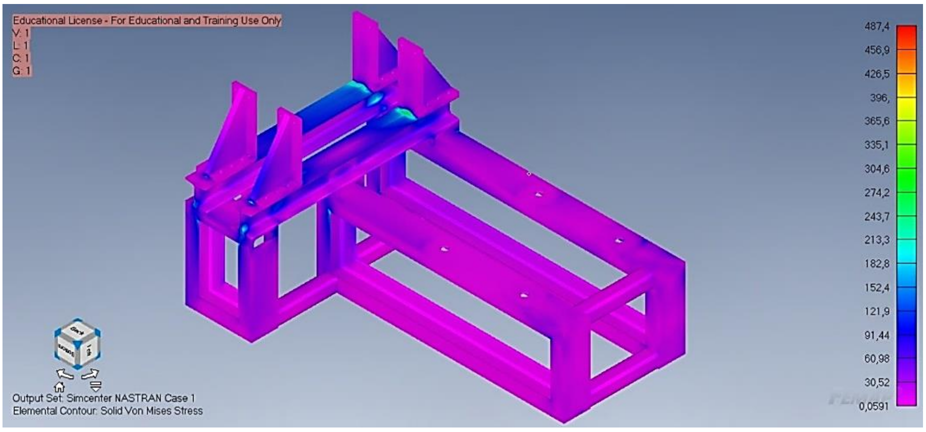

Fig. 7. Distribution of stresses in the frame and bearing supports of the PW280 press, version without reinforcements.

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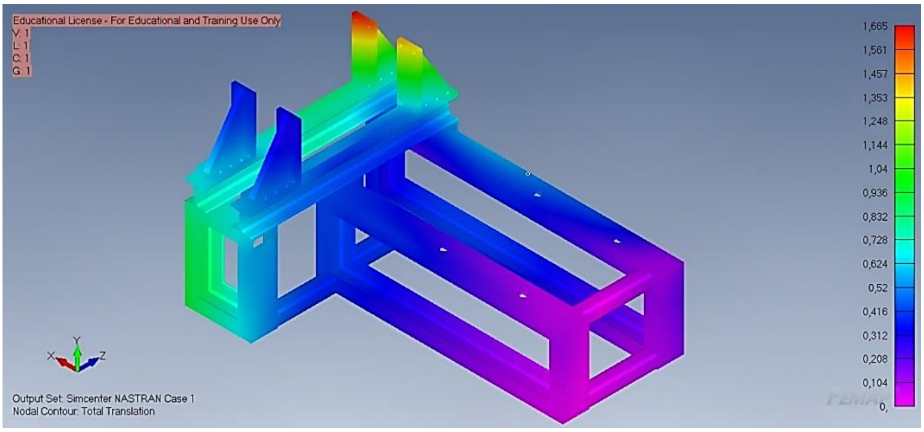

Fig. 8. Distribution of complete displacements in the frame and bearing supports of the PW280 press without reinforcements.

The maximum stress obtained in the tested structure reached about 487 MPa. It is very high and notably exceeds the material yield strength which is 275 MPa for the assumed material. One should note, however, that the stresses were located in places where bearing supports were connected to the briquetting machine frame and resulted from the simplification of the model and the replacement of bolted connections with welded connections. Therefore it can be concluded that, in the actual briquetting machine, maximum stresses can occur within the bolted connections. Additionally, these stresses will occur only when the motor generates the maximum torque and a 100 kN force pushing apart the rolls, occurring only in extreme and usually absent normal conditions of operation of the machine. It is also suspected that the simplifications of the model and the density of the applied finite element mesh might have had an effect on the high value of stresses. Additionally, due to the briquetting machine analysis based on the linear statics, the actual stress values may differ from those occurring in the real environment of its operation. The biggest displacement in this solution was 1.665 mm. It was in the upper part of the bearing support. According to calculations it causes the gap between the rollers to expand by about 0,8 mm. The deformation affected mainly the upper parts of the bearing supports on the drive system side. It must be pointed out, however, that such big displacements could occur because the model was fixed at two nodes of the frame mesh. Therefore the entire model was subject to considerable displacements against the fixed nodes.

Due to the occurrence of very high stresses and displacements in the model, it was decided to implement relevant modifications in the design in order to achieve higher rigidity. The biggest displacements took place in the upper part of the bearing supports and therefore it was necessary to introduce a reinforcement for these elements. In order to make the analysed design more rigid, it was decided to introduce two 9 mm diameter reinforcing steel rods with the mechanical property class 8.9 which were used to connect bearing supports (Fig. 9). Despite the bolted connection between the rod and the bearing support, it was decided to use an inseparable connection in the model. Results of the analysis for the reinforced design of the PW280 press are presented on Figures 10 and 11.

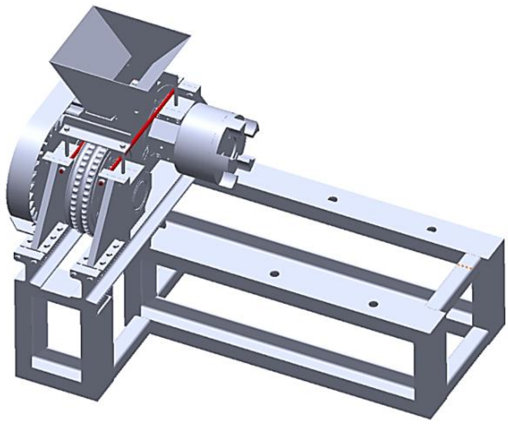

Fig. 9. The view of the reinforced rods (red color parts).

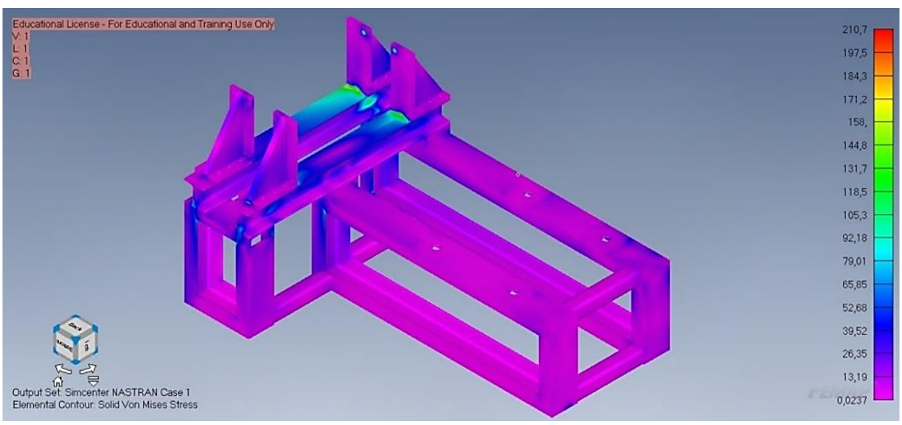

Fig. 10. Distribution of stresses in the frame and bearing supports of the PW280 press for the variant reinforced with 9 mm diameter rods.

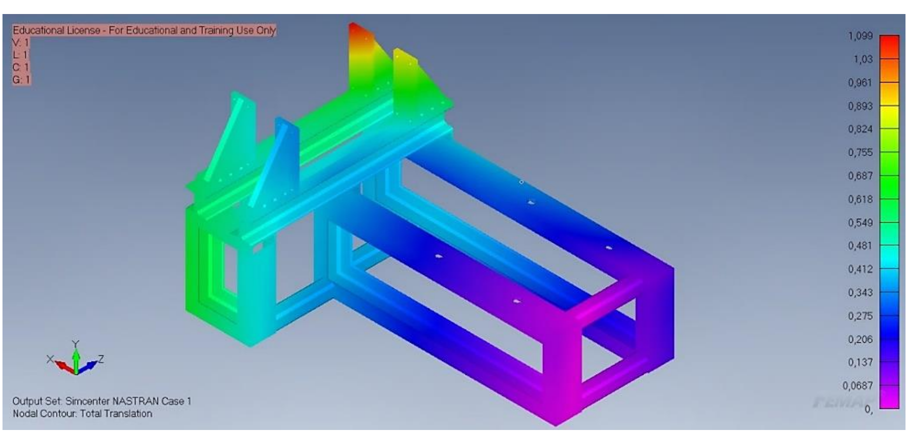

Fig. 11. Distribution of complete displacements in the frame and bearing supports of the PW280 press for the variant reinforced with 9 mm diameter rods.

Implementing the reinforced rods resulted in obtaining much lower values of stresses and displacements occurring in the model. The maximum stress in the structure was successfully reduced to about 211 MPa while it was about 314 MPa in the reinforcing rods, which was about 44% of their material yield strength. The maximum displacement in the reinforced structure was decreased to a level of 1.099 mm. It was also decided to run analyses for other modifications of the PW280 roller press design. The simulations were also run for reinforcement rods with a diameter of ø 12 or/and the bearing support thickness increased from 15 mm to 20 mm. The results of these analyses are summarised in Table 2.

Table 2. Comparison of maximum stresses and displacements for various design variants of the PW280 roller press.

Variant	Maximum stresses [MPa]	Maximum displacements [mm]
without reinforcements	487.4	1.665
reinforced with ø 9 rods	210.7	1.099
reinforced with ø 12 rods	182.8	0.964
increased thickness of supports	419	1.642
increased thickness of supports and reinforced with ø 9 rods	208.1	1.091
increased thickness of supports and reinforced with ø 12 rods	164.6	0.957

While analysing the obtained results, it can be noted that the implementation of reinforcements in the form of rods interconnecting bearing supports allows to make the PW280 press structure significantly more rigid. Using only an increased thickness of bearing supports reinforces the design to a small degree. The best solution used to reinforce the design is the variant with an increased thickness of supports and reinforcement with ø 12 rods. Such solution allowed to reduce stresses to a level of about 165 MPa.

Then, working roller cages, the designs of which consisted of three monolithic steel profiles, were analysed (Fig.12). This is a solution intended for briquetting machines with rollers placed outside the structure and it is present in the B220B, B400B and BH400CH models. The moulding rollers of B220B and B400B presses are arranged vertically while these of the BH400CH briquetting machine - horizontally. Figures 13 and 14 present distribution of stresses and displacements in the B220B press roller cage while figures 15 and 16 - that of the BH400CH press. The results of these analyses are summarised in table 4. In case of presses B220B and B400B, the upper beam of the working rollers cage was subject to the biggest displacements. The analysis produced the maximum stress in the working roller cage respectively of a value of 227.1 MPa and 286.1 MPa. They are situated within the connection of the roller cage upper beam to the vertical beam. The greatest displacement in the tested structures was 0.291 mm and 1.190 mm. The highest stress value obtained in the analysis of the BH400CH briquetting machine cage structure was 313.3 MPa and the displacement reached 0,587 mm. The highest stresses are situated in the place where elements of the cage are interconnected. Another group of presses covered by the analysis were the DH300, DH400, DH450 and DH500 briquetting machines. In designs of this type, the horizontally arranged moulding rollers are placed inside the briquetting machine cage. All presses have been designed in a similar way and their cages are made of profiles and channel sections sized to match the drive system and the moulding rollers.

Results of the analysis referring to the DH500 press as an example are presented on Figures 17 and 18.

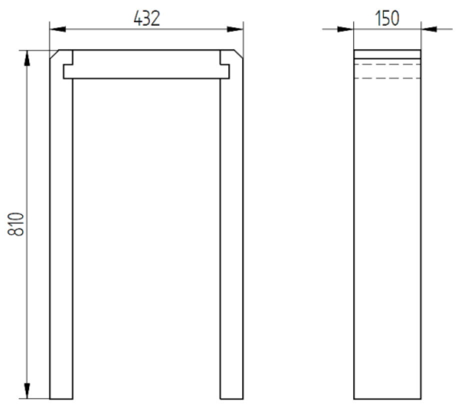

Fig. 12. The working cage view of the B220B roller press.

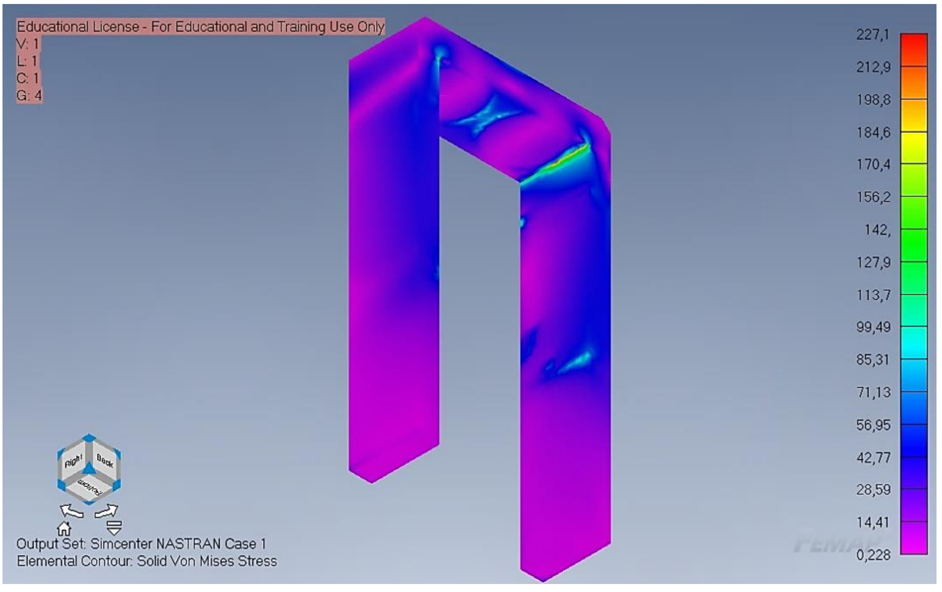

Fig. 13. Distribution of stresses in the B220B briquetting machine cage.

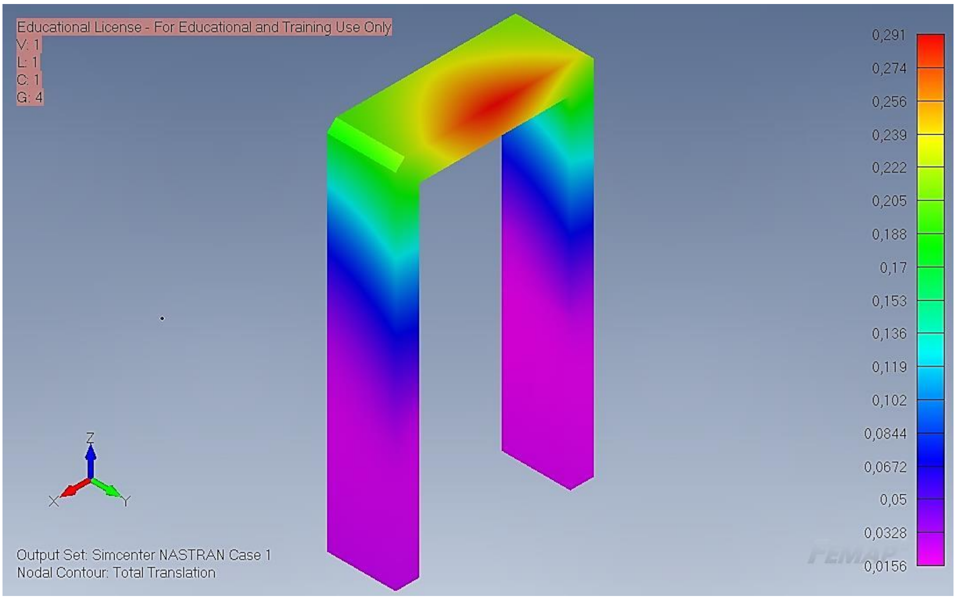

Fig. 14. Distribution of complete displacements in the B220B briquetting machine cage.

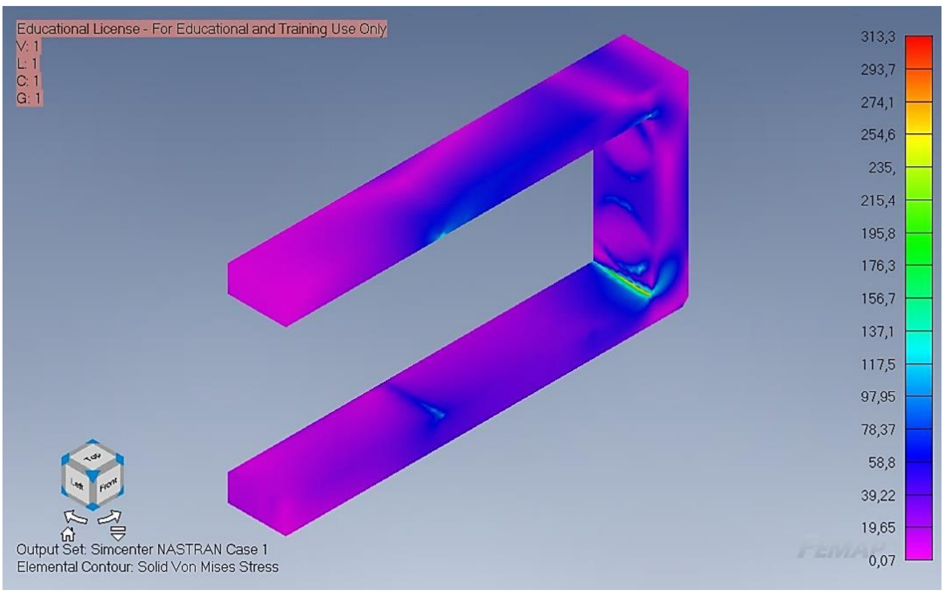

Fig. 15. Distribution of stresses in the BH4000CH briquetting machine cage.

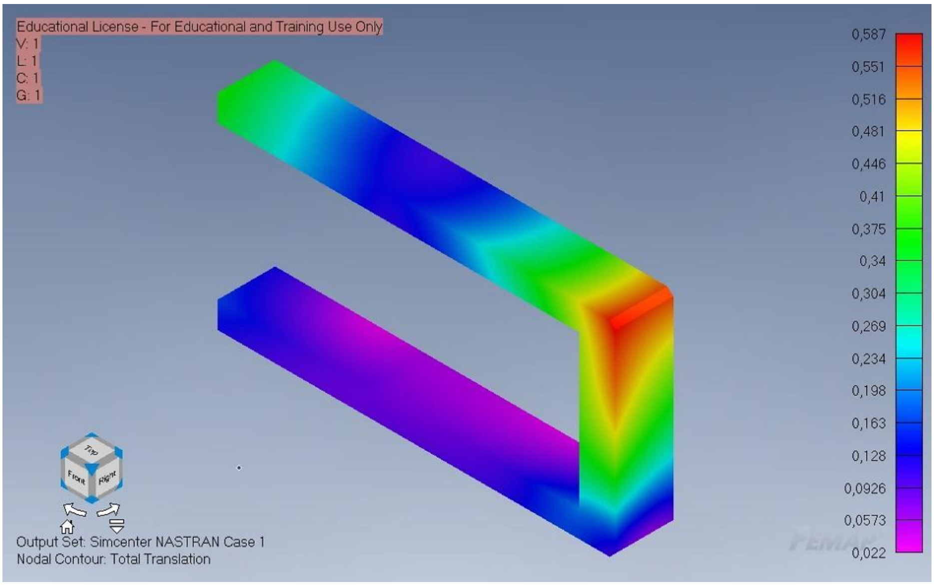

Fig. 16. Distribution of complete displacements in the BH4000CH briquetting machine cage.

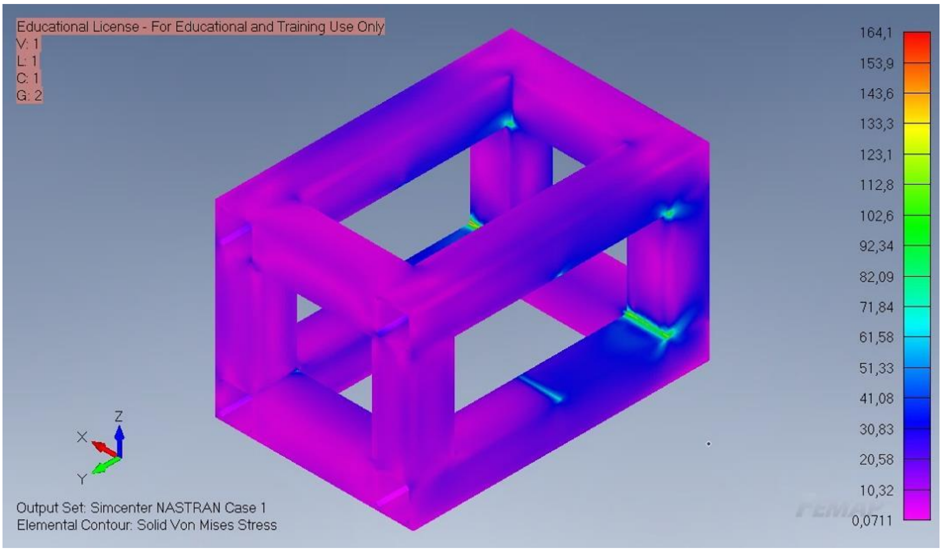

Fig. 17. Distribution of stresses in the DH500 briquetting machine cage.

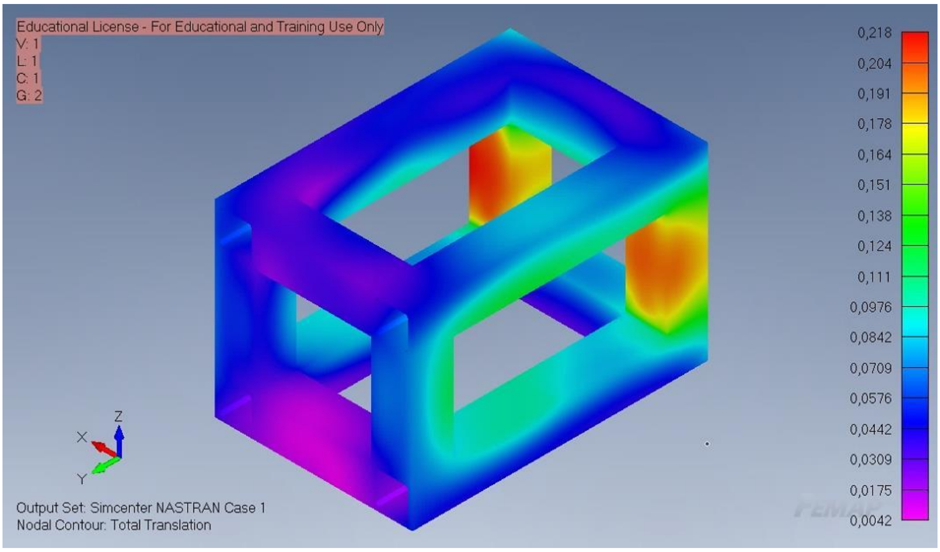

Fig. 18. Distribution of complete displacements in the DH500 briquetting machine cage.

Table 4. Comparison of maximum stresses and complete displacements for the inspected designs of briquetting machine cages.

Briquetting machine model	Arrangement of rollers	Maximum stresses	Maximum displacements
B220B	vertical	227.1	0.291
B400B	vertical	286.1	1.190
BH400CH	horizontal	313.3	0.587
DH300	horizontal	309.7	0.152
DH400	horizontal	231.1	0.111
DH450	horizontal	136.5	0.203
DH500	horizontal	164.1	0.218

In working roller cages of this type, values of the highest stress obtained range from 136.5 to 309.7 MPa and occur in places where the upper part of the cage is connected to the vertical profiles, on the roller side pressed by the roller pressure system. Meanwhile, the biggest displacement reaches a value ranging from 0.111 to 0.218 mm and is obtained in vertical profiles, on the pressed roller side.

5 Conclusions

Using the finite element method in engineering computations allows to considerably accelerate the process of designing and enhancing existing designs. The analysis of loads existing in roller presses have made it possible to assess their designs and to pave way to recommend solutions enabling modification of the tested designs in order to improve them. It should be noted, however, that the results of FEM analyses may be erroneous to a certain extent since simplified numerical models which are only an approximation to the actual arrangement have been used. Based on the obtained results, it can be concluded that the design of the working roller cage and the way in which the rollers are positioned against it have a considerable effect on its rigidity. When comparing all design solutions of the tested briquetting machines, it can be concluded that the best solution for high-capacity presses with high motive power values is to use roller cages with moulding rings provided in their centre. While comparing various design solutions being analysed, it can be noted that the cage designs in the DH series briquetting machines, apart from the DH300 press, are much more rigid than the other solutions. The DH450 and DH500 presses demonstrated the highest structural rigidity, although the highest loads occurred in these briquetting machines. There were also much smaller displacements of cage components in the DH series presses. The biggest displacements occurred in case of the solution used in the B400B roller press. The maximum displacement reached 1.19 mm. The material yield strength was not exceeded in any of the tested designs. However, the safety coefficient for the B400B, BH400CH and DH300 dropped below 1.5 to a level ranging from 1.1 to 1.3. The highest values of the safety coefficient were obtained for the DH type presses.

Acknowledgments

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