ANALIZA STRUCTURALĂ CU ELEMENTE FINITE A PIESELOR DE UZURĂ DE PE PLACA DE CONTRAPRESIUNE A UNEI AUTOGUNOIERE
FEM STRUCTURAL ANALYSIS FOR WEAR PARTS SUPPORTING COUNTERPRESSURE PLATE FROM A MUNICIPAL SOLID WASTE TRUCK

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Garbage trucks are used for the collection, compaction and transport of household waste, being equipped with complex systems that perform these functions. After the garbage is fed into the receiving tank, it is taken over by a compaction plate and inserted inside the dump truck where compaction is performed. As an element of back pressure, in the collection container is arranged a plate driven in translational motion by means of a telescopic cylinder with successive action. This counter-pressure plate is supported at the bottom on eight rectangular pieces from plastic and considered as wear parts. Paper presents the structural analysis of these wear parts. In the first phase of the study, three-dimensional parameterized modelling of each part of the assembly was performed (compaction plate, dump truck, compacted material, counterpressure plate and wear parts). After assembly, a dynamic simulation of the compaction process of household waste inside the dumpster was performed, and mechanical stresses on the wear parts, resulting from dynamic simulation, were imported into the Simulation, finite element analysis module of SolidWorks 2016 software. This is where the actual analysis was done, resulting in values and dispersion for equivalent stresses (calculated with the von Mises criterion), displacements, safety factor and relative deformations for these wear parts.

Autogunoierele sunt folosite pentru colectarea, compactarea și transportul deșeurilor menajere, ele fiind echipate cu sisteme complexe care îndeplinesc aceste funcții. După ce gunoiul este alimentat din pubelă în cuva de recepție, acesta este preluat de o placă de compactare și introdus în interiorul benei unde se realizează compactarea. Ca element de contrapresiune, în containerul de colectare este dispusă o placă acționată în mișcare de translație prin intermediul unui cilindru telescopic cu acțiune succesivă. Această placă de contrapresiune se sprijină la partea inferioară pe opt piese paralelipipedice executate din material plastic și considerate piese de uzură. Articolul prezintă analiza structurală a acestor piese de uzură. În prima fază a studiului s-a realizat modelarea parametrizată tridimensională a fiecărei piese a ansamblului (placă de compactare, benă, material de compactat, placă de contrapresiune și piese de uzură). După asamblare, a fost efectuată o simulare dinamică a procesului de compactare a deșeului menajer în interiorul benei, iar solicitările mecanice din piesele de uzură, rezultate în urma simulării dinamice, au fost importate în modulul de analiză cu elemente finite Simulation al software-ului SolidWorks 2016. Aici s-a realizat analiza propriu-zisă, rezultând valorile și dispersia pentru tensiunile echivalente (calculate cu criteriul von Misses), deplasările, coeficientul de siguranță și deformările relative pentru aceste piese de uzură.

Keywords: *FEM analysis, wear part, waste*

1. Introduction

The analysis of structures by the finite element method is more and more widespread in the last period. Design engineers perform modelling, simulation and analysis (with various CAD software) to various working bodies or even the ensembles before being sent to the actual execution. This gives a better picture of the behaviour of the structures in various working conditions, but also allows the correction of possible design errors. Analysis of garbage trucks and transport of municipal solid waste trucks it is found in many specialized papers that present the results obtained by analysis with FEM of various parts or subassemblies, [1–9], but none shows the analysis of the wear parts on which the counterpressure plate rests.

The purpose of this finite element 3D numerical simulation study was to simulate the mechanical behaviour of the eight wear parts on which the counterpressure plate rests at the bottom, following the stresses that arise during the process of compacting household waste at a municipal solid waste truck Valu€Pak 1000 (Norba, Suedia), considering for this that the wear parts are made of two different plastics (Nyaltron GSM and Nylon 101).

The waste compaction system of such a machine consists of two basic parts, a metal plate with articulated support that takes the material from the feeding area of the machine, having a complex movement, and a counterpressure plate disposed in the parallelepiped collecting container (see Fig. 1).

Important stresses appear in both parts during the collection and compaction process, but much larger in the pushing and picking piece when feeding the container. At discharging, the counterpressure plate has high stresses because it has to push the entire amount of material from the

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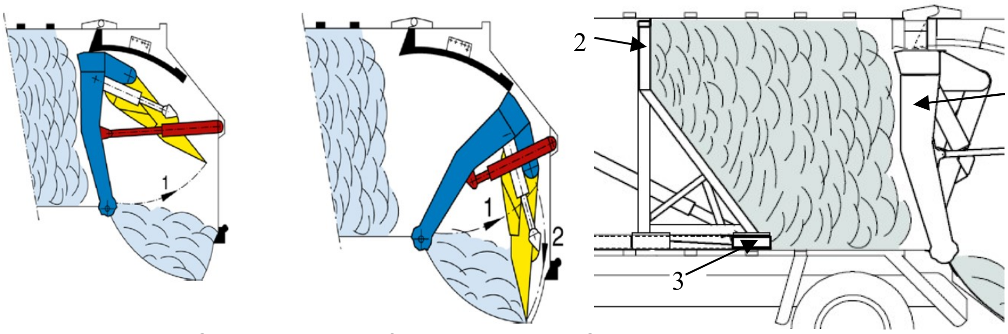


Fig. 1 - Compaction system for waste at the Valu€ Pak 1000 garbage truck, [10].
Sistemul de compactare al gunoiului menajer la autogunoiera Valu€ Pak 1000
1-compacting plate, 2-counterpressure plate, 3-waste part; *1-placă de compactare, 2-placă de contrapresiune, 3-piesă de uzură.*

container, the more uneven the more inhomogeneous is material on the cross section of the collection container. Wear parts have the highest probability of failure in the compaction assembly shown above.

2. Materials and Methods

In the first stage of this study, the three-dimensional geometric model of the components of the assembly was made (compression plate, counterpressure plate, wear part and garbage truck container). For this purpose, was used a laptop with Intel Core i5-3210M processor, 2.5 GHz, an NVIDIA GeForce GT 630M video card with 2 Gb of own memory, the laptop's RAM being 8 Gb. 3D modelling was performed using the parameterized design program SolidWorks Premium 2016 S.P. 0.0.

Three-dimensional modelling of assembly components was performed in the "Parts" module of the design program, in Fig. 2 presenting the isometric view of the wear part, as well as the interface of the Solid Works program.

The pieces were introduced in the Assembly module of the program where they were positioned by adding geometric relationships between their entities (relations of concentricity, coincidence and parallelism between edges and faces). It should be noted that the wear part was inserted eight times in assembly, because so many are in fact at the model analysed. For the dynamic simulation of the household waste compaction process, between the two plates (compacting and counterpressure) the material to be compacted was also parameterized, Fig. 3. For this, a thickness at the bottom of about 580 mm was chosen.

The entire assembly of Fig. 3 was introduced in the Motion Study module to perform the dynamic simulation of the garbage compaction process. For this purpose it was considered that the back pressure plate is fixed, together with the material to be compacted, and the compacting plate moves towards it. According to [12] the speed of movement of the compactor plate without load is of maximum 150 mm/s, at the beginning of

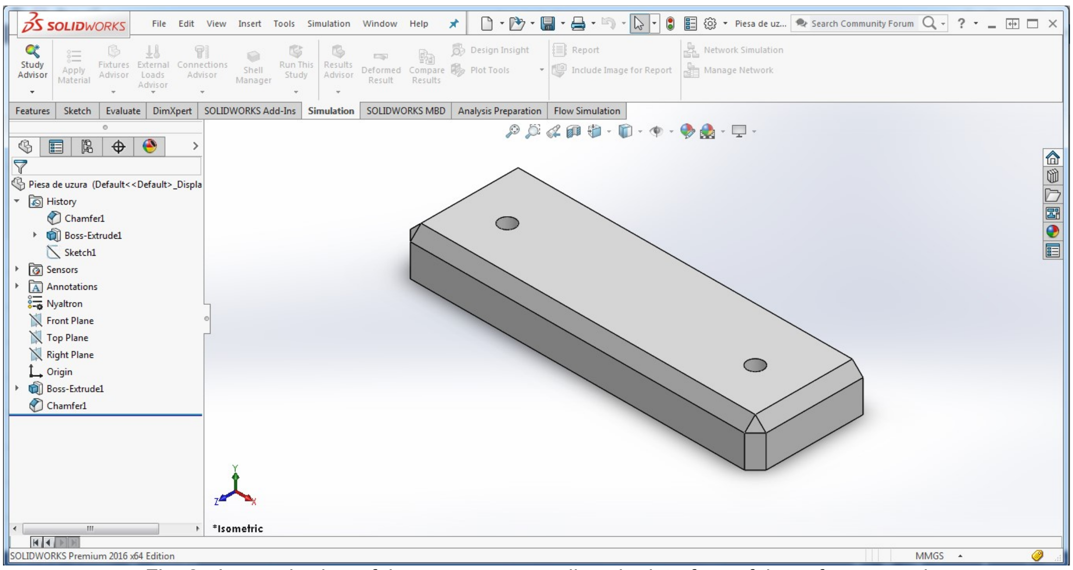


Fig. 2 - Isometric view of the wear part as well as the interface of the software used
Vedere izometrică a piesei de uzură precum și interfața software-ului utilizat

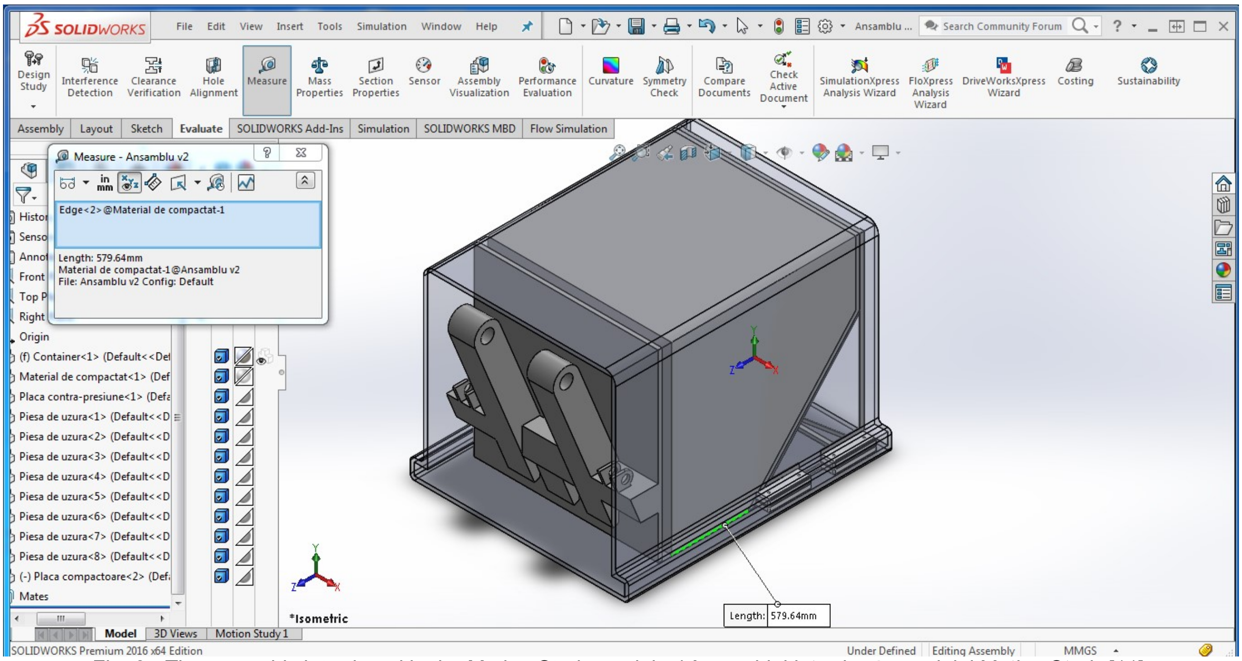


Fig. 3 - The assembly introduced in the Motion Study module / *Ansamblul introdus în modulul Motion Study* [11].

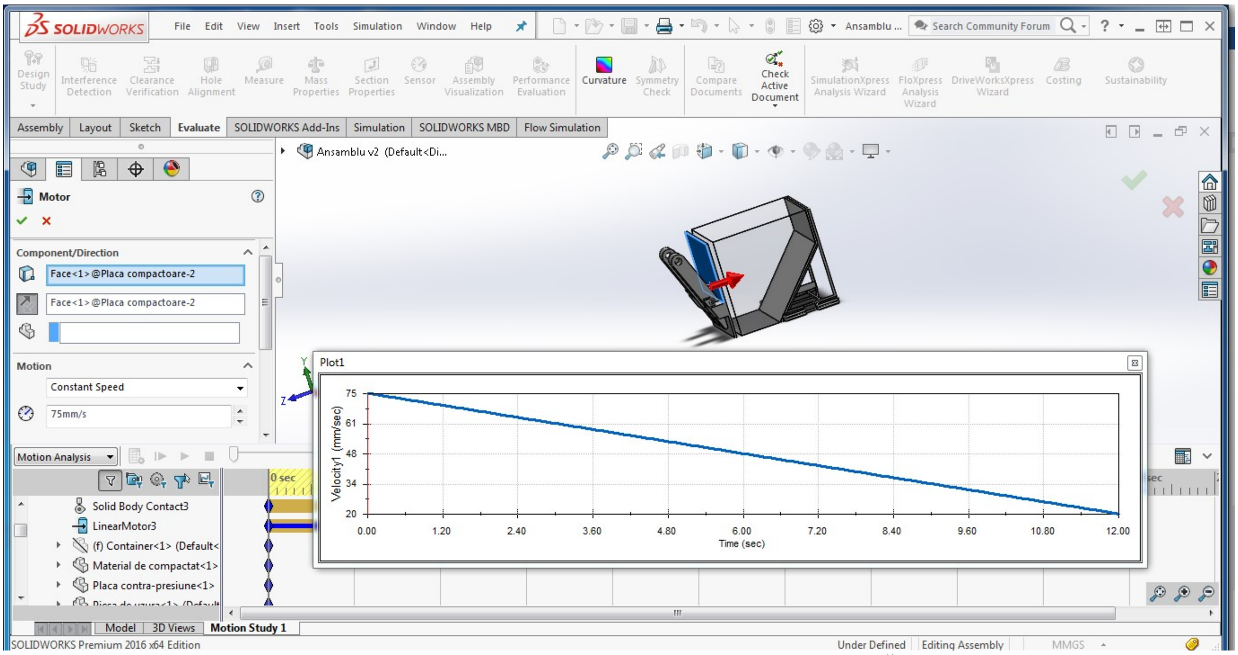


Fig. 4 - Linear motor attached to the compacting plate,/ *Motorul liniar atașat plăcii compactoare* [11].

the compaction speed is 75 mm/s and reaches the end of compaction at 20 mm/s. Thus, a linear motor with variable speed was attached to the compaction plate (see Fig. 4). It should also be mentioned that the calculation period (dynamic simulation) was of 12 s.

Following the dynamic simulation, the values of the stresses in the parts of interest were obtained (wear parts). So, in Fig. 5 the variation curve of the reaction force between the material and the counterpressure plate is presented. Peaks are observed on the reaction force variation curve due to uneven compaction of the material.

After completing this step, proceeded to the next step which was to import the stresses for the 3D geometric models of the eight wear parts in the "Simulation" module of the Solid Works design program.

According to the manufacturers' data sheets, the materials most often used in the manufacture of wear parts are polyamides Nyaltron GSM and Nylon 101. In Fig. 6 the fatigue curve of these plastics is shown, and Table 1 shows the material characteristics.

Before proceeding to the presentation of the finite element analysis, the numbering and positioning of the analysed wear parts must be shown. As mentioned above, there were eight in total, on them resting the back pressure plate in its movement inside the dump truck, both when loading the container with household waste and when unloading it. They are fastened with screws

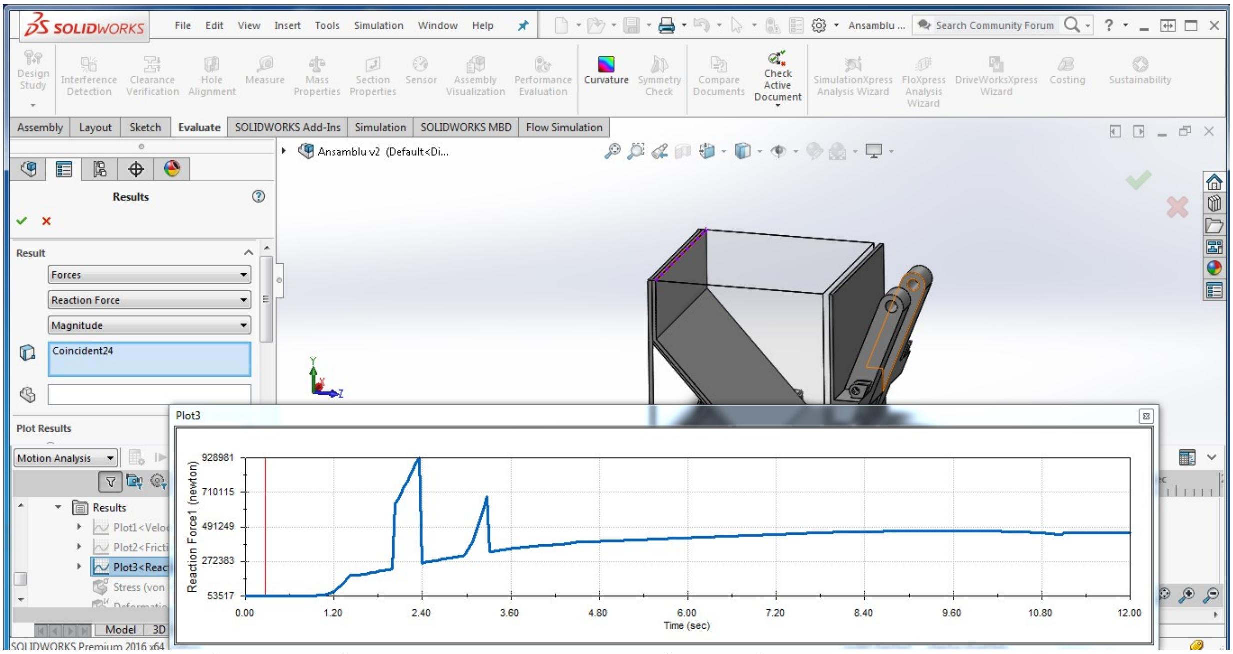


Fig. 5 - Variation of the reaction force in the counterpressure plate / *Variația forței de reacțiune din placa de contrapresiune*.

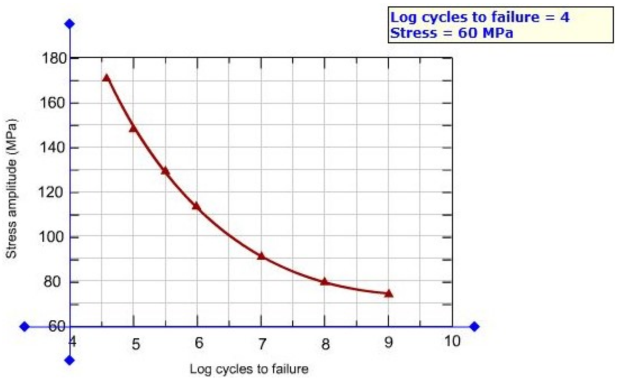


Fig. 6 - Fatigue curve for the two plastics used to make the wear part / *Curba de oboseală pentru cele două materiale plastice folosite la execuția piesei de uzură* [13].

Table 1

Mechanical properties of Nylatron GSM and Nylon 101 polyamides / *Proprietățile mecanice ale poliamidelor Nylatron GSM și Nylon 101* [14,15]

Property	Nylatron GSM	Nylon 101
The modulus of elasticity, N/mm^2	3400	1000
Poisson's ratio, -	0.28	0.3
Shear modulus, N/mm^2	3200	-
Density, kg/m^3	1160	1150
Tensile strength, N/mm^2	82	79.3
Yield point, N/mm^2	80	60
Coefficient of thermal expansion, 1/K	$8 \cdot 10^{-5}$	$1 \cdot 10^{-6}$
Thermal conductivity, W/(m·K)	0.3	0.53
Specific heat, J/(kg·K)	1500	1500

to the lower part of the counterpressure plate and are arranged four on one side and another four on the other side. Behind the counterpressure plate is the driver's cab, so it can be said that wear parts 5, 6, 7 and 8 are on the left side of the garbage truck and wear parts 1, 2, 3 and 4 are on the right side. In Fig. 7 the arrangement of the wear parts in the counterpressure and discharge plate assembly is shown.

Before presenting the results of the analysis it should be mentioned that 16 analyzes were run for the eight wear parts (for stresses from dynamic simulation for each of the two types of materials considered - Nyaltron GSM and Nylon 101). Total analysis time (dynamic simulation + the 16 finite element simulations) it was about 46 hours. Also, it must also be said that in the same compacting process, the eight wear parts behave differently. Having different stresses, was chosen analysis of each piece.

3. Results and Discussions

The discrete finite element model of a wear part is shown in Fig. 8. After discretizing the finite element network, the simulation was run, its results being presented below.

Following the simulation, the design program provided the results obtained in graphical form; the geometric pattern is divided into areas of a certain colour, each area comprising the region of the geometric pattern in which the analysed size has the value specified in the color legend on the right side of the screen. For the modeled and analyzed wear part model, the results obtained after the simulation in Solid Works are presented below. Thus, in Fig. 9 the values of the displacements that appear in the wear parts during the previously defined stresses are presented.

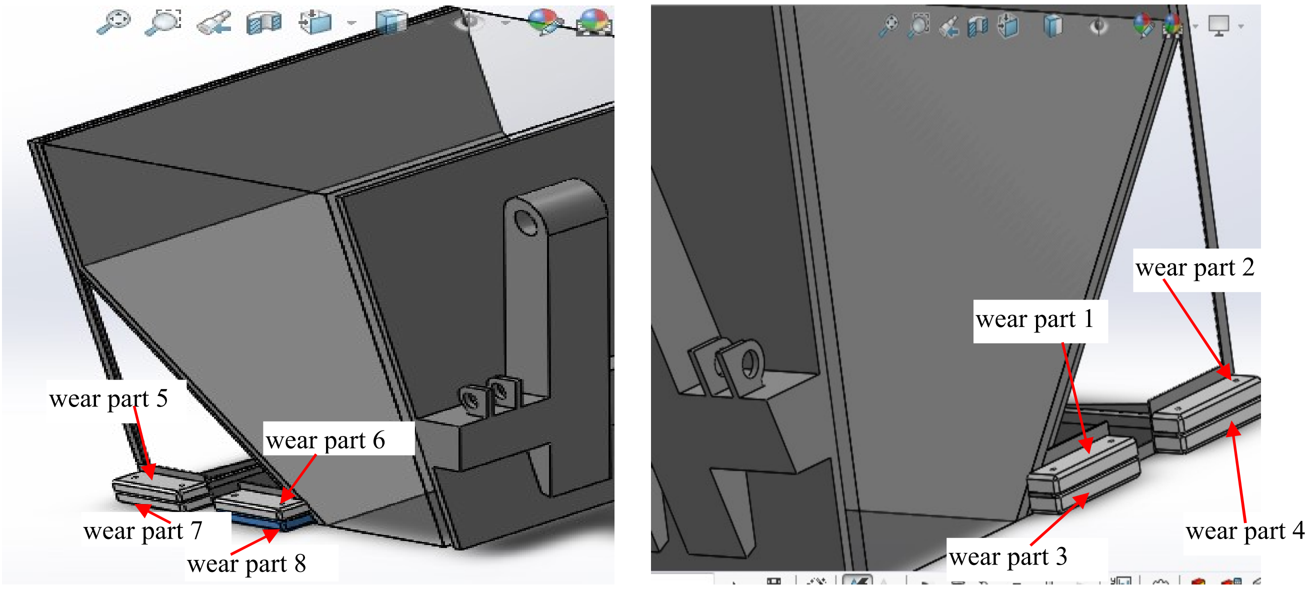


Fig. 7 - Arrangement of wear parts / *Dispunerea pieselor de uzură.*

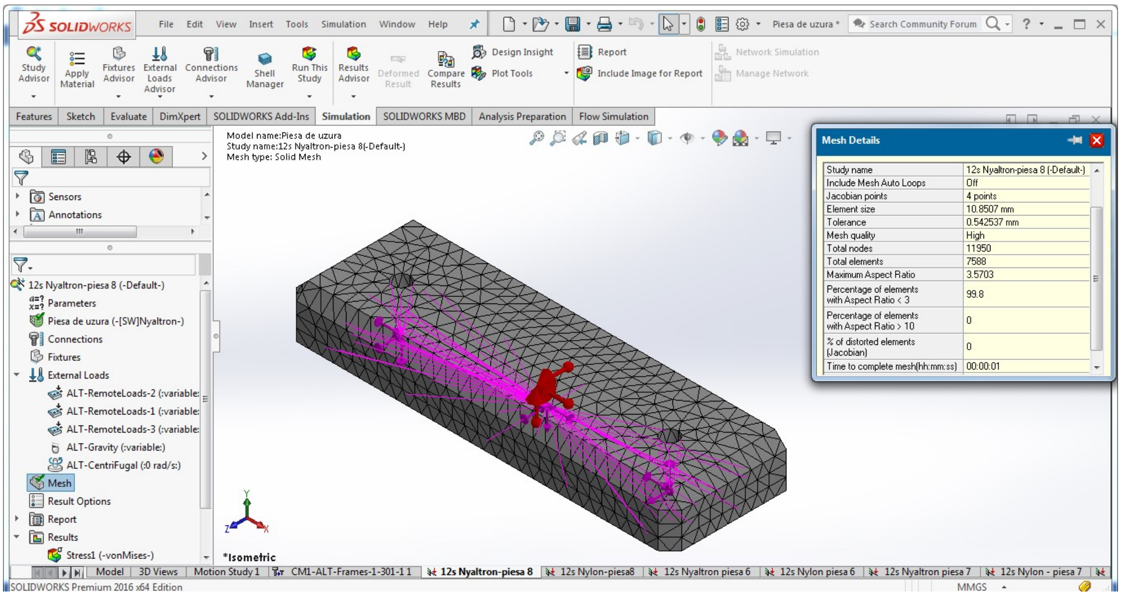
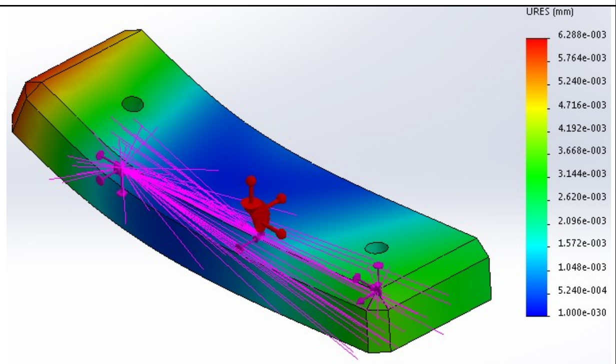
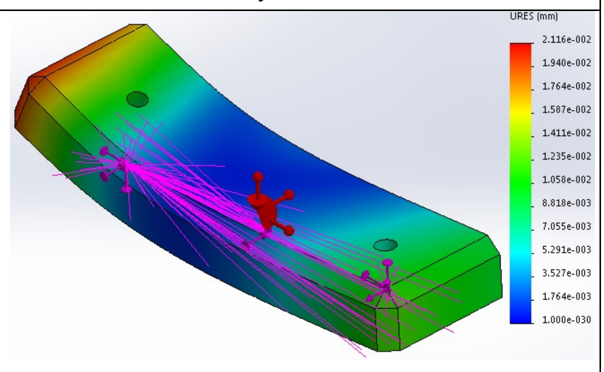
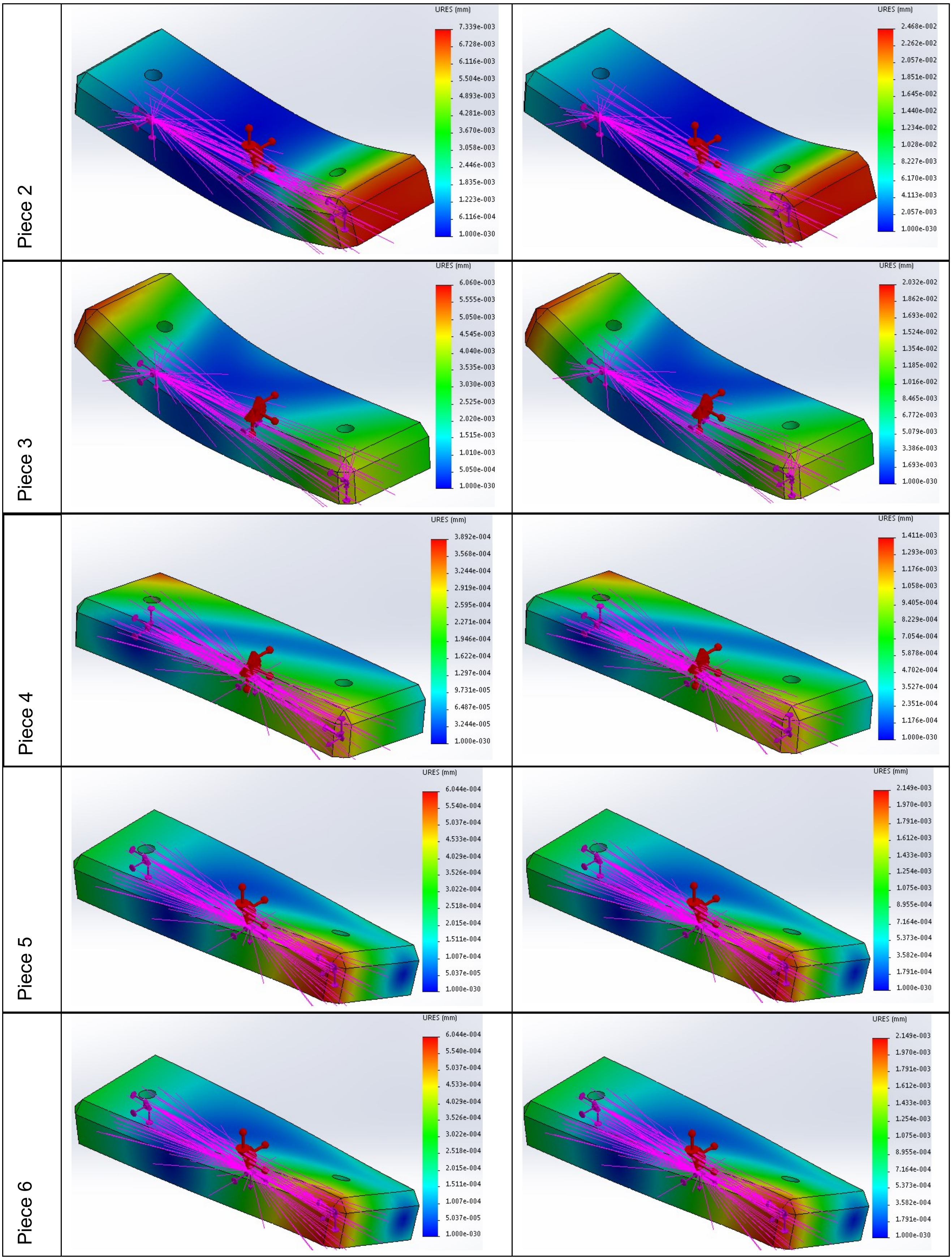


Fig. 8 - Discretization with finite elements of the geometric model / *Discretizarea cu elemente finite a modelului geometric.*

	Nyaltron GSM	Nylon 101
Piece 1		


Piece 2
URES (mm)
7.339e-003
6.728e-003
6.116e-003
5.504e-003
4.893e-003
4.281e-003
3.670e-003
3.058e-003
2.446e-003
1.835e-003
1.223e-003
6.116e-004
1.000e-030
URES (mm)
2.468e-002
2.262e-002
2.057e-002
1.851e-002
1.645e-002
1.440e-002
1.234e-002
1.028e-002
8.227e-003
6.170e-003
4.113e-003
2.057e-003
1.000e-030
Piece 3
URES (mm)
6.060e-003
5.555e-003
5.050e-003
4.545e-003
4.040e-003
3.535e-003
3.030e-003
2.525e-003
2.020e-003
1.515e-003
1.010e-003
5.050e-004
1.000e-030
URES (mm)
2.032e-002
1.862e-002
1.693e-002
1.524e-002
1.354e-002
1.185e-002
1.016e-002
8.465e-003
6.772e-003
5.079e-003
3.386e-003
1.693e-003
1.000e-030
Piece 4
URES (mm)
3.892e-004
3.568e-004
3.244e-004
2.919e-004
2.595e-004
2.271e-004
1.946e-004
1.622e-004
1.297e-004
9.731e-005
6.487e-005
3.244e-005
1.000e-030
URES (mm)
1.411e-003
1.293e-003
1.176e-003
1.058e-003
9.405e-004
8.229e-004
7.054e-004
5.878e-004
4.702e-004
3.527e-004
2.351e-004
1.176e-004
1.000e-030
Piece 5
URES (mm)
6.044e-004
5.540e-004
5.037e-004
4.533e-004
4.029e-004
3.526e-004
3.022e-004
2.518e-004
2.015e-004
1.511e-004
1.007e-004
5.037e-005
1.000e-030
URES (mm)
2.149e-003
1.970e-003
1.791e-003
1.612e-003
1.433e-003
1.254e-003
1.075e-003
8.955e-004
7.164e-004
5.373e-004
3.582e-004
1.791e-004
1.000e-030
Piece 6
URES (mm)
6.044e-004
5.540e-004
5.037e-004
4.533e-004
4.029e-004
3.526e-004
3.022e-004
2.518e-004
2.015e-004
1.511e-004
1.007e-004
5.037e-005
1.000e-030
URES (mm)
2.149e-003
1.970e-003
1.791e-003
1.612e-003
1.433e-003
1.254e-003
1.075e-003
8.955e-004
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1.000e-030

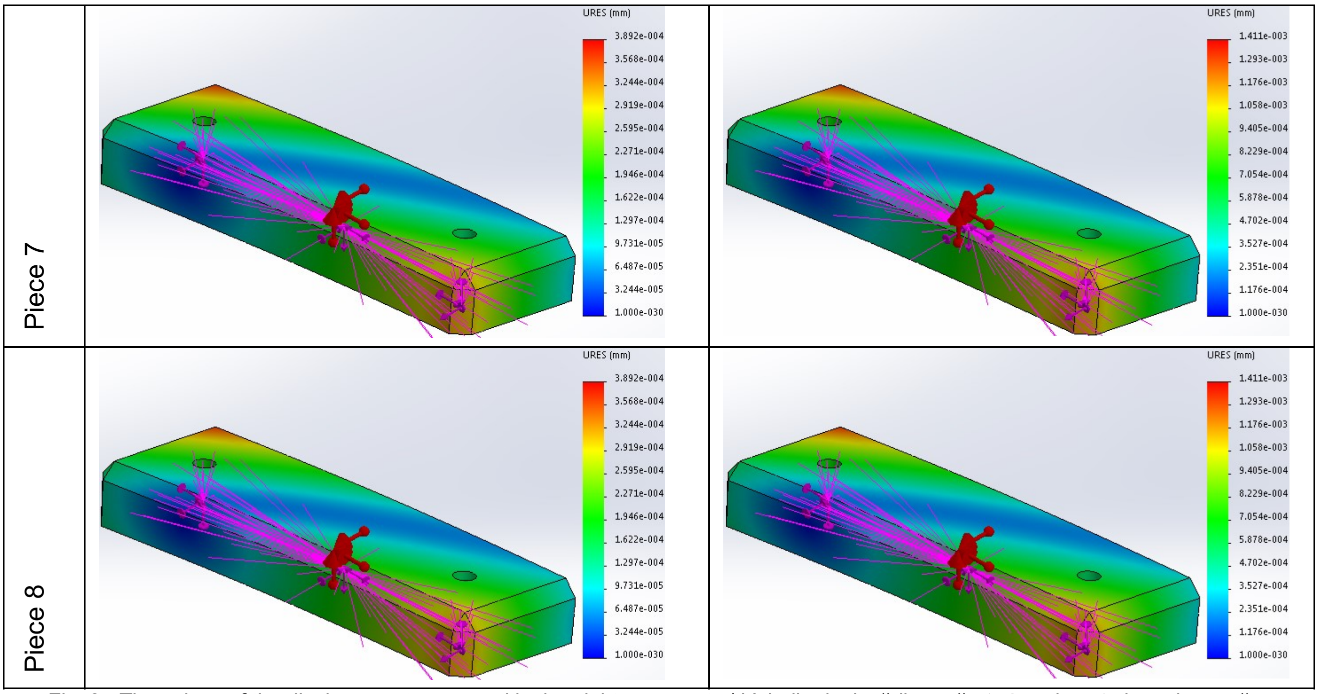
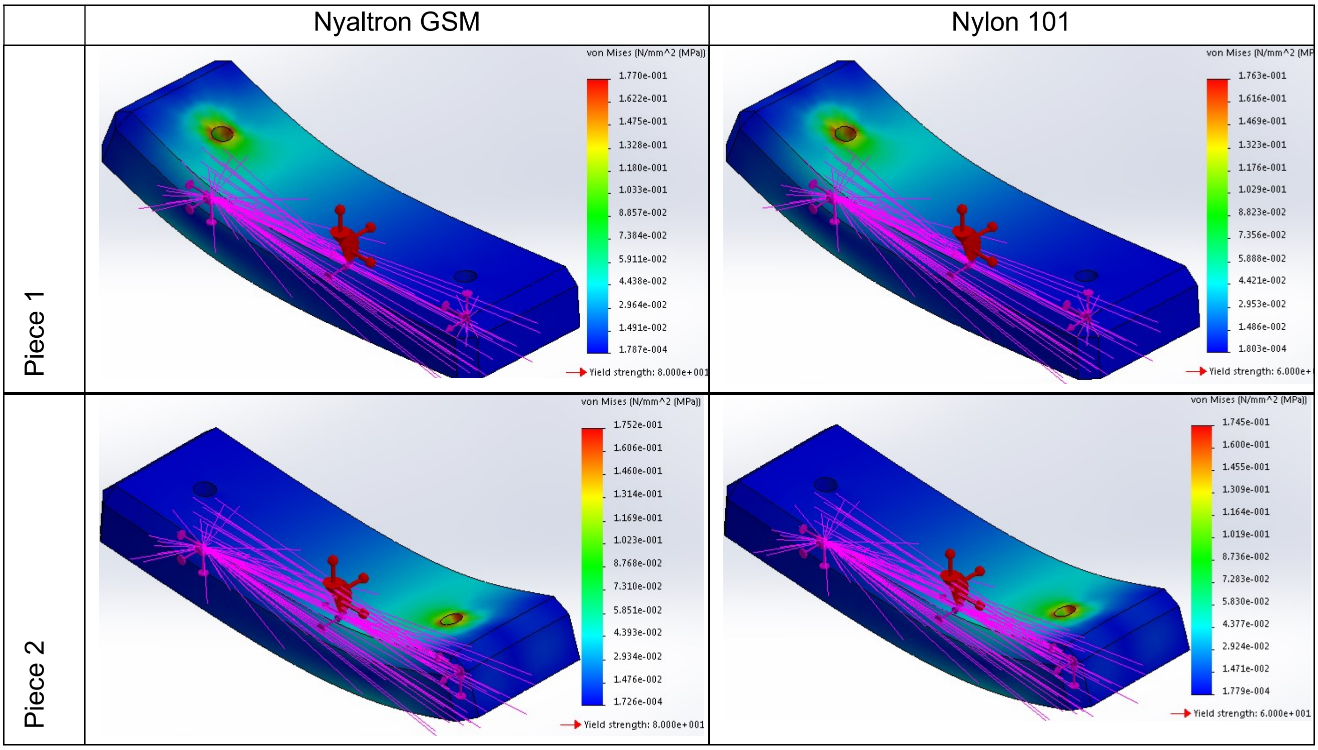
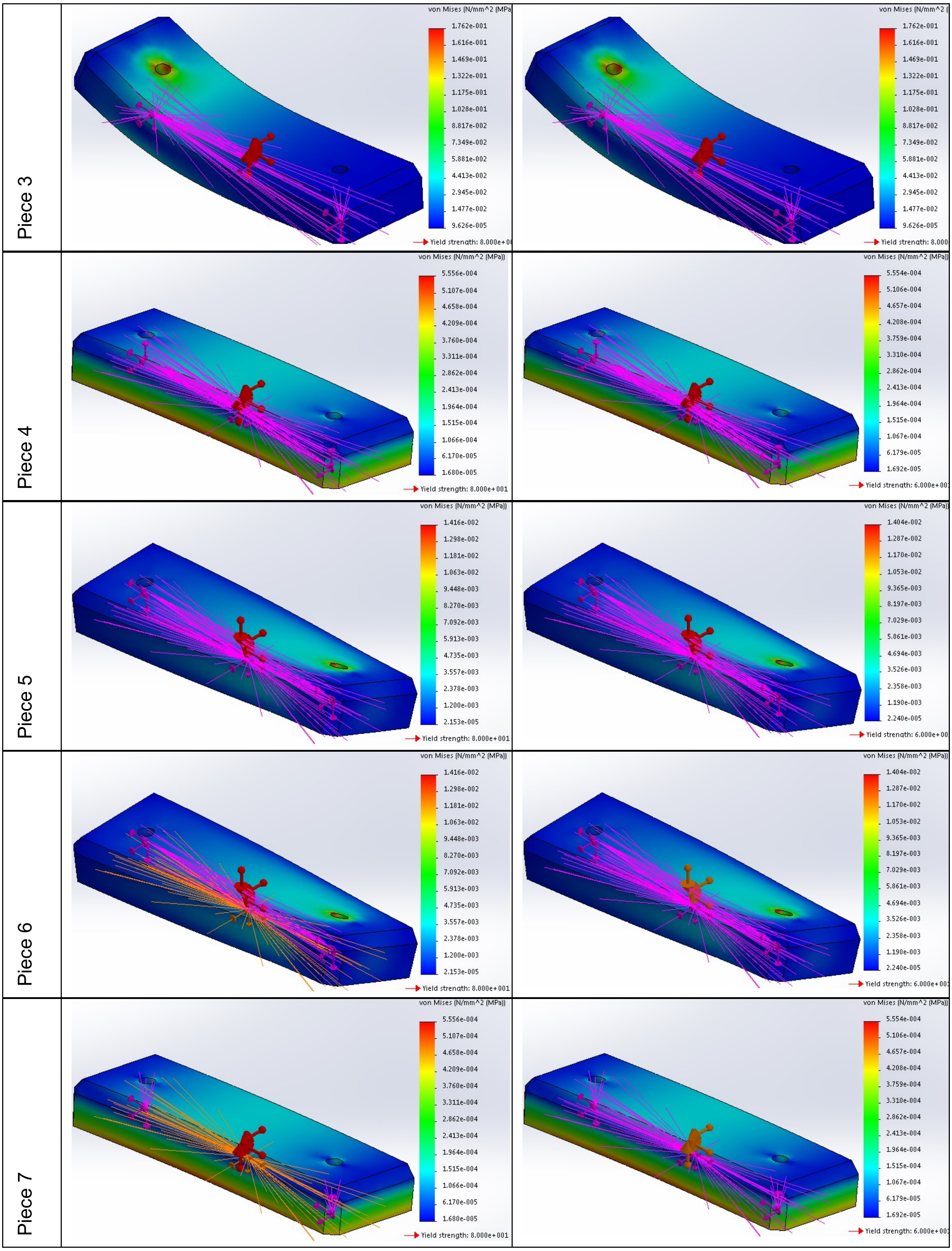


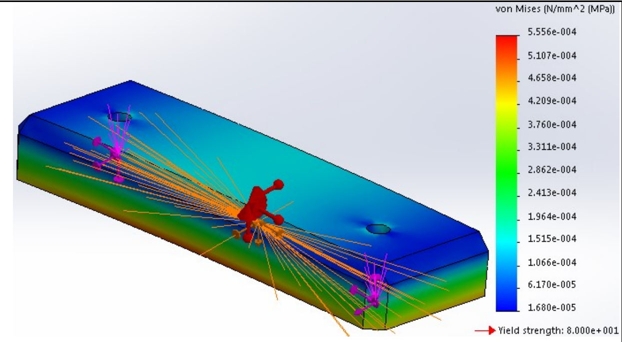
Fig. 9 - The values of the displacements occurred in the eight wear parts / *Valorile deplasărilor apărute în cele opt piese de uzură.*

Analysing this data, it can be seen that the values of the displacements are close and small, for the two types of materials considered the maximum displacement value is found in the case of piece 2, $7.34 \cdot 10^{-3}$ mm for Nyaltron GSM and $2.47 \cdot 10^{-2}$ for Nylon 101. In Fig. 10 the values of the equivalent stresses from the eight wear parts for the two materials considered are presented, stresses calculated according to the von Mises criterion.




Piece 3
Piece 4
Piece 5
Piece 6
Piece 7
von Mises (N/mm^2 (MPa))
1.762e-001
1.616e-001
1.469e-001
1.322e-001
1.175e-001
1.028e-001
8.817e-002
7.349e-002
5.881e-002
4.413e-002
2.945e-002
1.477e-002
9.626e-005
5.556e-004
5.107e-004
4.658e-004
4.209e-004
3.760e-004
3.311e-004
2.862e-004
2.413e-004
1.964e-004
1.515e-004
1.066e-004
6.170e-005
1.680e-005
Yield strength: 8.000e+001
5.554e-004
5.106e-004
4.657e-004
4.208e-004
3.759e-004
3.310e-004
2.862e-004
2.413e-004
1.964e-004
1.515e-004
1.067e-004
6.179e-005
1.692e-005
Yield strength: 6.000e+001
1.416e-002
1.298e-002
1.181e-002
1.063e-002
9.448e-003
8.270e-003
7.092e-003
5.913e-003
4.735e-003
3.557e-003
2.378e-003
1.200e-003
2.153e-005
1.404e-002
1.287e-002
1.170e-002
1.053e-002
9.365e-003
8.197e-003
7.029e-003
5.861e-003
4.694e-003
3.526e-003
2.358e-003
1.190e-003
2.240e-005

Piece 8



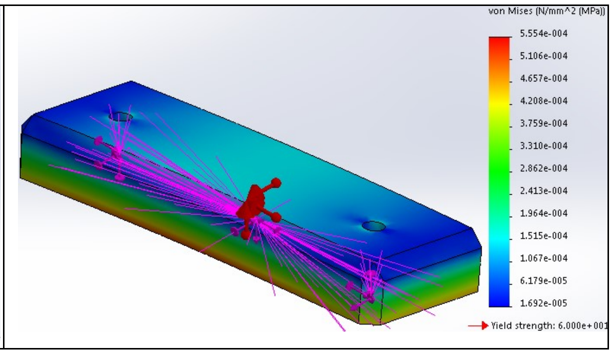
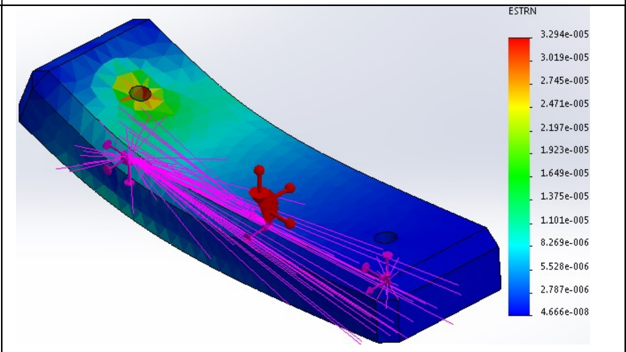


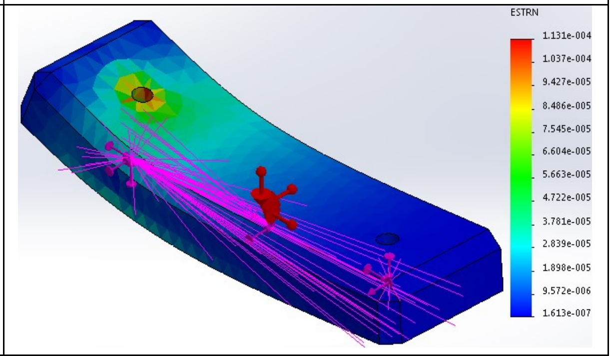
Fig. 10 - Equivalent stress values according to the von Mises criterion appeared in the eight wear parts
Valorile tensiunilor echivalente după criteriul von Mises apărute în cele opt piese de uzură.

Analysing the figure it can be seen that all eight pieces behave differently in the same regime, and the stress values are well below the breaking stresses of the two materials. The maximum equivalent stress value is reached for the piece 1, $1.77 \cdot 10^{-1}$ MPa for Nyaltron GSM and $1.76 \cdot 10^{-1}$ MPa for Nylon 101.

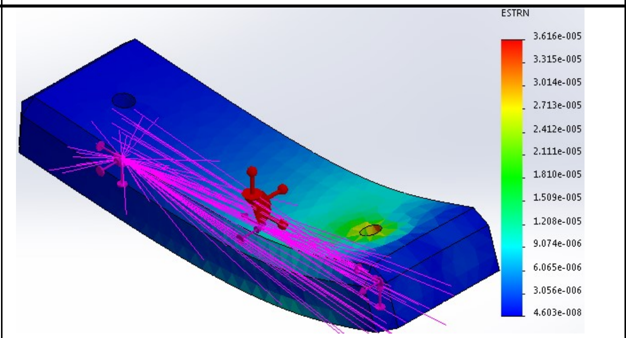
	Nyaltron GSM	Nylon 101

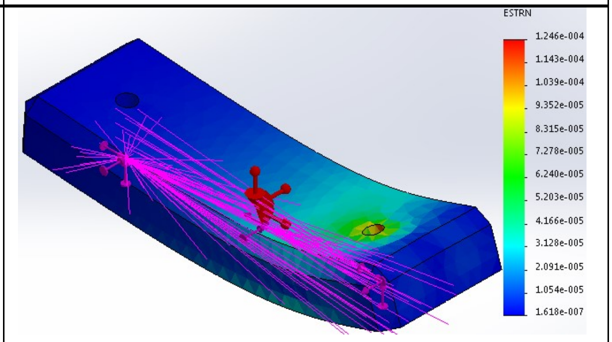
Piece 1



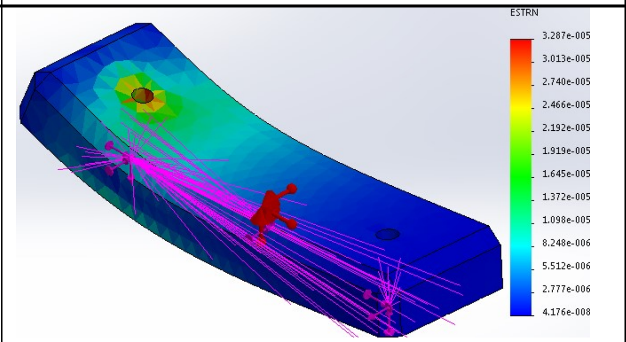


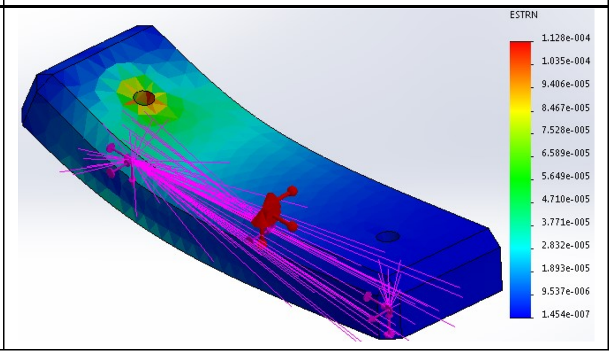
Piece 2





Piece 3





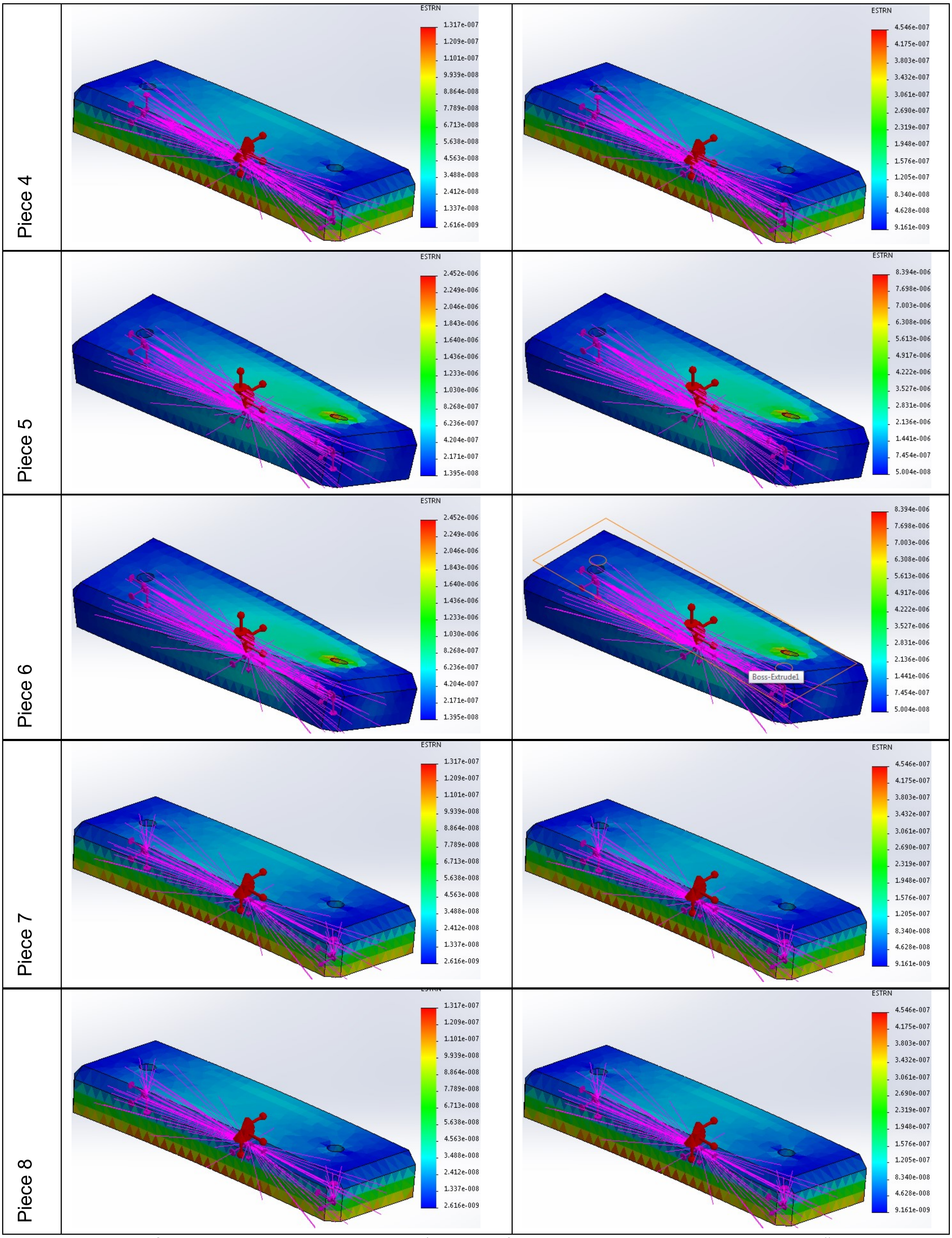


Fig. 11 **-** Equivalent deformation values in the eight wear parts / *Valorile deformațiilor echivalente în cele opt piese de uzură.*

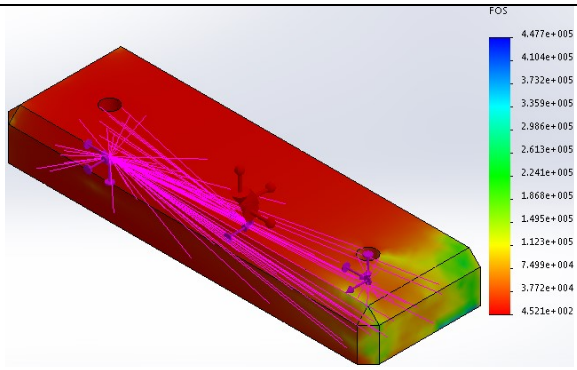
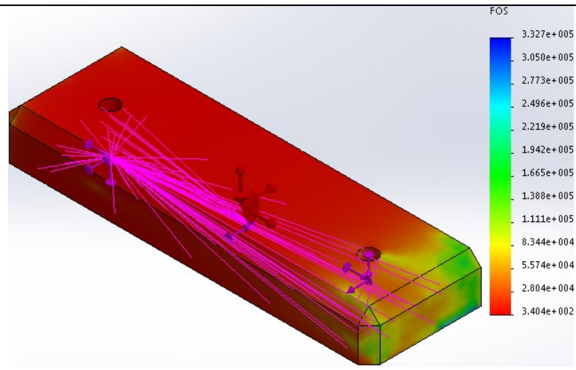
<table>
<tr><td></td><td>Nyaltron GSM</td><td>Nylon 101</td></tr>
<tr><td>Piece 1</td><td>
</td><td>
</td></tr>
</table>

Fig. 12 - Minimum values of the safety factor / *Valorile minime ale coeficientului de siguranță.*

Analysing Fig.11 the values of the equivalent deformations that appear in the eight wear parts can be observed, for the two materials used in the study. Thus, the maximum equivalent deformation arises in piece 2, $3.62 \cdot 10^{-5}$ for Nyaltron GSM and $1.25 \cdot 10^{-4}$ for Nylon 101.

The value of the safety factor was also drawn from the finite element analysis. Thus the minimum value of the safety factor is reached for part 1 and are presented in fig. 12. For comparison, for agricultural machinery intended for ploughing, the safety factor takes values between 1.8 and 2.2, [16].

4. Conclusions

The minimum values of the safety factor are 454 for Nyaltron GSM and 340 for Nylon 101. We deduce from this that the wear parts work in quite difficult conditions, hence the high failure rate in them. In addition to having to support the weight of the counterpressure plate to which is added an additional weight of household waste that rests on this plate, the wear parts also withstand the friction from the moments of sliding the counterpressure plate (when compacting garbage and when emptying the garbage truck).

The analysis also showed that stress points appear in the structure of the wear parts, generally located in the areas where the screw and nut assembly is performed on the counterpressure plate. The maximum values of the equivalent stress calculated with the von Mises criterion are reached in the case of part 1, $1.77 \cdot 10^{-1}$ MPa for Nyaltron GSM and $1.76 \cdot 10^{-1}$ MPa for Nylon 101, values below the yield point of these materials. Having obtained these values, further a design analysis can be done, with the same software used in the analysis, in order to reduce the stresses in the wear parts and, so, increase in life span.

The results presented in this paper may help designers and manufacturers of garbage compaction machines, but not only.

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