USING HYDRAULIC PRESSES FOR FINDING THE STIFFNESS VARIATION OF THE WASTE MATERIALS - EXPERIMENTS FOR CALIBRATING SIMULATIONS

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Given the growing intensity of recycling nationally and globally, the waste compaction process is becoming more and more important. Waste compaction and baling reduce their volume. This paper presents the modelling and simulation of hydraulic systems of two stationary presses (HSM V-605 and Strautmann PP-1208), as well as the experimental validation of the results obtained from the simulations. For HSM V-605 the maximum force was calculated in the simulation with an error of 0.53% compared to the actual maximum force, and for the Strautmann PP-1208 press the maximum force was calculated in the simulation with an error of 1.15% compared to the maximum actual force. At the same time, the profile of the hydraulic oil pressure curves for the two presses was established, as well as the mathematical laws that best represent the variation of the force with the displacement of the piston.

Keywords: Hydraulic press systems, FluidSIM, oil pressure profile variation

1. Introduction

Waste management refers to temporary storage, reuse, collection, transport, treatment, recycling and disposal of waste, the main purpose being to save raw materials by reusing recyclable waste, thus contributing to reducing the pressure on natural resources. The highest volume of waste in the world is plastic waste, and in recent years improvements have been made to its recovery and recycling, [1,2]. In contrast, paper waste (compared to petroleum waste) has advantages such as:

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biodegradability, recyclability, good printability, "green" image and regenerability, [3]. Both types of waste are some of the most recycled in Romania. Every year, many companies in the recovery and recycling network incur significant costs associated with the collection, sorting and recycling of used polymer packaging and PET bottles, [1,2,4-6].

Plastics, such as polyethylene terephthalate, polycarbonate and melamine, can be recycled by using them in building concrete or mortars in the form of granules or small particles as sand substitutes, [6-9].

In Europe, recycling has increased by almost 20% in recent decades, to around 72% in 2012, [10]. With the increase in recycling rates, technological processes have also been improved.

In a circular economy an important practice is recycling, currently considered the main core for the return of materials in the supply chain, and the main bottleneck in the plastic and paper recycling chains is the lack of continuous selective collection programs with an emphasis on environmental education processes, [11,12].

Waste compaction and packaging reduce their volume and have similar benefits. The process depends on the material being reduced and what is going on with it. Waste cardboard or polyethylene terephthalate (PET) can be both packaged and compacted.

Bale is a process that compresses the material into a block (bale) that is secured with plastic tape or wire. Packaging reduces the volume of waste, which has a number of advantages: it reduces the space occupied and the packaging is easier to store and transport due to its regular shape, thus reducing storage, transport and disposal costs.

Recycling cardboard waste also reduces energy consumption and emissions compared to the production of new materials. Under high pressure, cardboard waste can usually be compacted with a compaction ratio of 6:1, and the bales can be immediately recyclable.

There are horizontal or vertical compaction balers. The most commonly used waste balers are vertical balers, which compress the material from top to bottom, with a top opening on the front for material feeding and a door at the bottom that opens to allow the bale produced to be placed on a pallet.

The drive systems of these compact balers are usually hydraulic systems.

A hydraulic drive system is a technical system consisting of several elements that convert mechanical energy into hydraulic energy, which it transmits in various places of use, where it converts it again into mechanical drive energy. The transmission of hydraulic energy can be done directly or following a manual or automatic control.

Hydraulic drive systems (see fig. 1) are generally made up of a pump, which converts the mechanical energy of a termic or electric motor into hydraulic energy, various control elements (various valves, hydraulic directional control valve, etc.) which directs the working fluid on various routes, from one or more hydraulic motors that transform hydraulic energy into mechanical drive energy and various auxiliary elements (such as filters, oil tank, pipes, fittings, hydraulic accumulators, measuring elements, etc.).

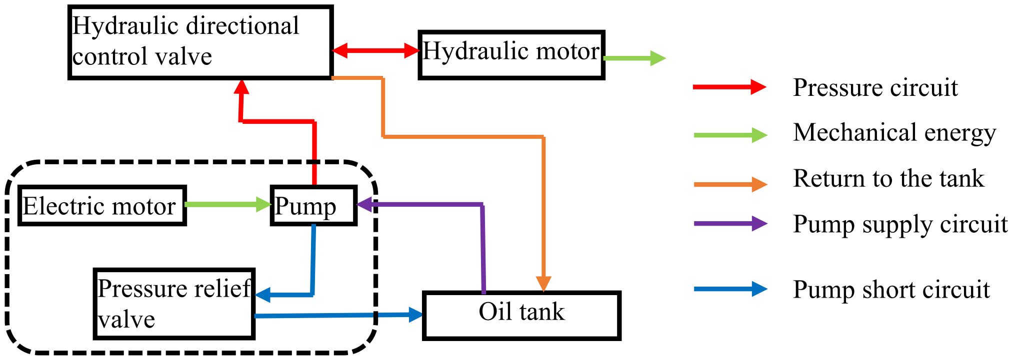

Fig. 1. Simplified diagram of a hydraulic circuit, [13]

Simulation and modelling of hydraulic systems is increasingly used in the technical community, [14-17]. At present, research on hydraulic systems consists mainly in solving the problems of energy dissipation and reliability, [18].

One of the most used software for simulations and modelling of hydraulic and pneumatic systems is FESTO FluidSIM. The mathematical equations behind the simulations in FluidSIM they are well known in specialized literature and are presented in the bibliographic references [19-26].

In practice, the results obtained in modelling in FluidSIM have some discrepancies compared to the experimental determinations and the general mathematical representation of a hydraulic system, [19]. Therefore, this paper aims to determine the differences between simulation and reality for two stationary presses, the results obtained after the simulation being experimentally validated. The purpose is to determine the confidence level of the results of a simulation in FluidSIM.

2. Material and method

Stationary press hydraulic systems (HSM V-605 and Strautmann PP-1208) analyzed in this paper are open type hydraulic systems. This type of system is characterized by the fact that the hydraulic pump draws the hydraulic oil from a tank and directs it at a certain pressure to a hydraulic motor (hydraulic cylinder, rotary motor or oscillating motor) which converts hydraulic energy into mechanical energy, and from here the oil returns to the tank.

The hydraulic system of the HSM V-605 stationary press (made in FluidSIM) is presented in fig. 2. It consists of an actuating unit (consisting of an oil tank, a hydrostatic pump with a theoretical flow rate of 3.9 l/min driven by a 1.5 kW electric motor and a supply voltage of 380 V, and a pressure relief valve that opens at 290 bar), a hydraulic directional control valve with three positions and four ways, a check valve, an adjustable throttle valve and a double-acting hydraulic cylinder. For information on modeling in FluidSIM, the authors consulted the source [27].

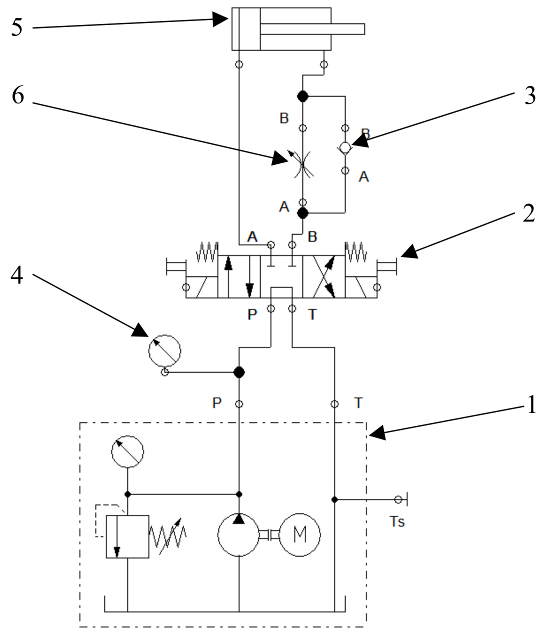

Fig. 2. Hydraulic diagram of the HSM V-605 stationary press
1-actuating unit; 2- hydraulic directional control valve; 3- check valve; 4-manometer; 5-double-acting hydraulic cylinder, 6 – adjustable throttle valve

The hydraulic directional control valve, electrical actuation with solenoid and return with spring. In the left position (fig. 2) the hydraulic directional control valve will drive the hydraulic oil from the pump to the chamber in front of the piston and the oil from the chamber behind the piston to the tank, so that the rod will come out of the cylinder. In the right position the hydraulic directional control valve will drive the oil from the pump to the chamber behind the piston and the oil from the chamber in front of the piston to the tank, so that the rod will enter the cylinder.

According to the technical book, [28], the maximum stroke of the piston is 620 mm, the piston has a diameter of 50 mm and the rod has a diameter of 40 mm. In reality, however, the piston stroke is controlled by the oil pressure in the hydraulic system. As long as the pressure does not exceed 290 bar, the stroke can be maximum, but if the pressure exceeds 290 bar, the oil coming out of the pump outlet will be directed by the pressure relief valve to the tank.

In fig. 3 Strautmann PP-1208 stationary press hydraulic system (also made in FluidSIM) is presented. It consists of two actuating units (each consisting of an oil tank, a hydrostatic pump, powered by a 4 kW electric motor and a supply voltage of 380 V, and a pressure relief valve), a hydraulic directional control valve with three positions and four ways, two one-way valves and a double-acting hydraulic cylinder.

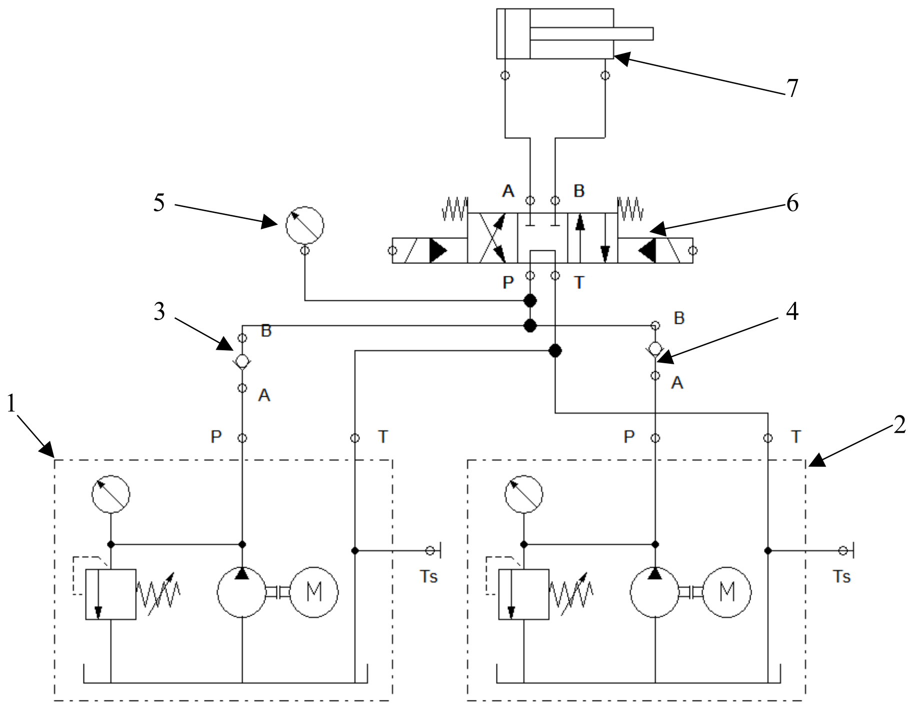

Fig. 3. Strautmann PP-1208 stationary press hydraulic diagram
1-actuating unit 1; 2 – actuating unit 2; 3,4- check valve; 5- manometer; 6- hydraulic directional control valve; 7- double-acting hydraulic cylinder

The solenoid controlled pilot hydraulic operated valve is actuated by the increasing pressure, and the return is also here with spring. In the left position, the hydraulic directional control valve will drive the hydraulic oil from the pump (s) to the chamber behind the piston and the oil from the chamber in front of the piston to the tank, so that the rod will enter the cylinder. In the right position the hydraulic directional control valve will drive the oil from the pump to the chamber in front of the piston and the oil from the chamber behind the piston to the tank, so that the rod will come out of the cylinder.

It can be seen from fig. 3, that this stationary press has two actuating units working in parallel. Actuating unit 1 it has a pump with a flow rate of 11.2 l/min and a pressure relief valve of 230 bar, and actuating unit 2 it has a pump with a flow rate of 38 l/min and a pressure relief valve of 60 bar. Initially, both actuating units pump oil to the hydraulic cylinder. When the oil pressure at the outlet of the pump drain pipe from actuating unit 2 reaches (and exceeds) the value of 60 bar, the pressure relief valve will short-circuit the pump of actuating unit 2 to the tank. Thus, only actuating unit 1 (with 230 bar pressure relief valve) will introduce oil into the system.

The maximum stroke of the piston is 890mm, the piston has a diameter of 180 mm and a shaft of 100 mm diameter, [28]. Here, too, the stroke of the piston can be controlled by the pressure in the hydraulic system, which can have a maximum stroke only if the pressure in the system does not reach the opening pressure of the pressure relief valve of the actuating unit 1 (230 bar).

The internal leaks of the hydraulic pumps used in the two simulations were set to the value 0.04 l/(min·MPa).

The authors determined the variation of the force with the displacement of the piston, the conditions of experimentation being published in the papers [29,30] and the complete experimental data were also published there. In paper [29] experimental data were taken on the pressing of polyethylene terephthalate waste, and in paper [30] data from the pressing of paper and cardboard waste. In the simulations, the hydraulic cylinder of the HSM V-605 press was set to compact a mass of 7.75 kg, and that of the Strautmann PP-1208 press to compact a mass of 80.5 kg, in order to comply with the experimental conditions.

3. Results and discussions

After modelling the two hydraulic systems, the simulation was run, the results being presented in figures 4 and 5.

The simulation results are presented in graphical form, in the two figures you can see the variation in time of the position, speed and acceleration of the piston, the force exerted by it when moving the load, the position of the directional control valve and the hydraulic oil pressure at the inlet of the directional control valve from the hydraulic pump.

It can be seen from fig. 4 that the speed at the exit of the piston from the cylinder is lower (0.03 m/s) than the speed at the entrance to the cylinder (0.09 m/s) for HSM V-605 press. This is mainly due to the compacted material which tends to relax by pushing the piston into the cylinder and thus increasing its retraction speed. While in the Strautmann PP-1208 press (fig.5) the two speeds are equal and considerably lower than in the first press (0.01 m/s).

Also from the speed graph of the piston on the two strokes it can be seen that there is a non-uniformity degree of the oil flow at both presses, the speed not being constant. Non-uniformity degree can be calculated with the relation, [13]:

$$\delta = \frac{Q_{max} - Q_{min}}{Q_{med}} \cdot 100 = \frac{v_{max} - v_{min}}{v_{med}} \cdot 100, \% \tag{9}$$

Extracting the three speeds (maximum, minimum and average) from the graph of speed variation over time (fig.4 and fig. 5) the non-uniformity degree of the oil flow was calculated.

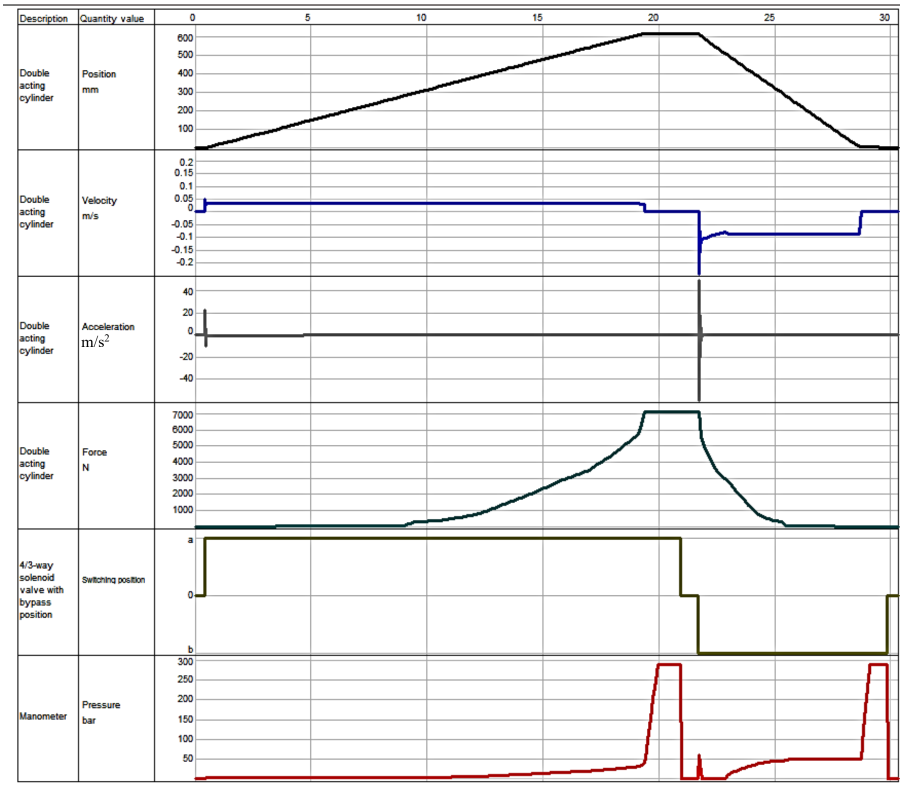

Fig. 4. HSM V-605 numerical simulation results

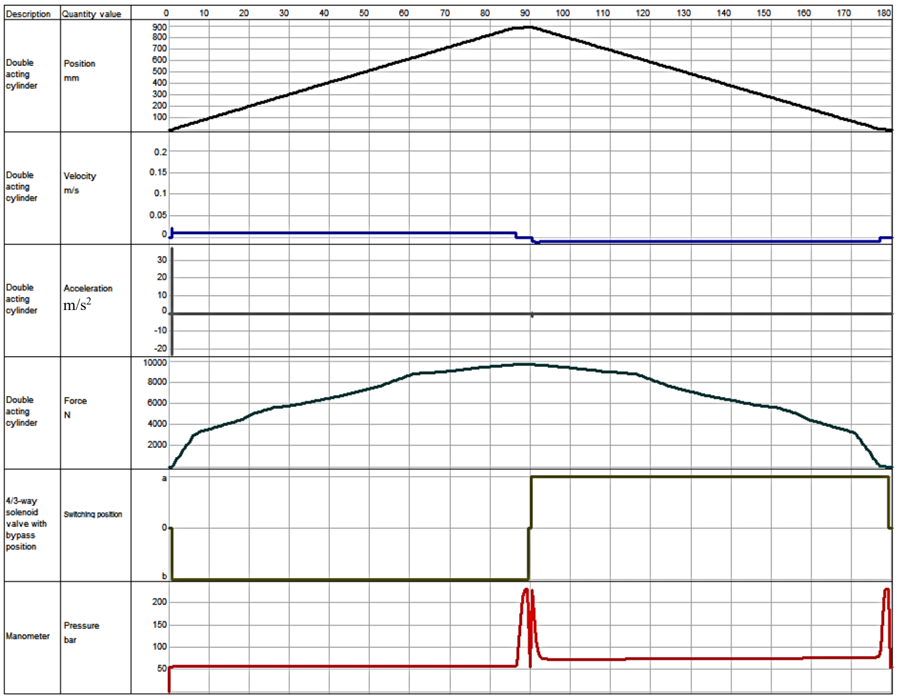

Fig. 5. Strautmann PP-1208 numerical simulation results

Thus, at the exit of the rod from the cylinder, the degree of non-uniformity is of maximum 86.2%, and at the entrance of the rod in the cylinder is 93.1% for the HSM V-605 press. While at Strautmann PP-1208 the degree of non-uniformity of the flow is on both races of 70%.

It should be noted that this degree of non-uniformity of the flow lasts a maximum of 1.5 s at the beginning of each piston stroke (either exit or retract from / into the cylinder), then becoming uniform, and the speed constant. This is usually due to starting loads.

Charts of oil pressure variation on the pump discharge line (fig. 4 and 5) shows us that most of the time the pressures are constant for the Strautmann press (57.67 bar on the exit stroke from the cylinder of the rod and 74.22 bar on the cylinder inlet stroke of the rod) and it will increase towards the end of the stroke until the open pressure of the pressure relief valve (230 bar). In contrast, the HSM V-605 press has different profiles of the pressure variation curve for the two piston strokes. On the rod exit stroke from the cylinder, about half from the stroke the pressure is constant at 4.6 bar, then increase exponentially until the pressure in the system controlled by the pressure relief valve is reached (290 bar). On the retraction stroke it is observed that the pressure variation is logarithmic.

It can be concluded that a greater number of pumping elements leads to a lower degree of non-uniformity of the flow, instead a pump with an odd number of pistons generates a much more uniform flow, the approximate relationship for its determination being the one developed by Ackerman. By properly dephasing the operation of the chambers, the non-uniformity of the flow rates can be reduced to acceptable values for the installation. The non-uniformity of flows can also be reduced with hydropneumatic accumulators (hydrophores).

Charts of force variation over time for the two presses, on both strokes of the piston shows exponential variations up to the maximum force of 7118.2 N for HSM V-605 press and 9702.1 N for Strautmann PP-1208 press (simulated values).

Table 1

Variation of force relative to piston stroke at stationary presses HSM V-605 and Strautmann PP-1208

HSM V-605	Experiments	Piston displacement, mm	From [29]	275	294	323	351	383	419	463	502	537	575	605	620
		Force, N		51.7	147.1	283.8	455.9	787.6	1191.1	2006.6	2884.5	3473.2	4258.0	5690.3	7156.2
	Simulation	Piston displacement, mm		281	300	326	363	391	420	468	504	541	575	612	620
		Force, N		60	327.3	347.3	572.7	818.2	1309.1	2127.3	2863.6	3436.6	4418.2	5727.3	7118.2
Strautmann PP-	Experiments	Piston displacement, mm	From [30]	42	120	188	254	325	401	462	544	613	693	782	890
		Force, N		4021.8	4690.5	5193.2	5714.6	5900.6	6337.5	6874.7	7669.1	8757.7	8960.3	9325.7	9591.3
	Simulation	Piston displacement, mm		63	186	210	264	317	386	451	538	627	703	801	890
		Force, N		3201.5	4498.6	5003.8	5600.3	5834.7	6340.4	6807.4	7623.7	8821.9	8998.1	9436.5	9702.1

As previously mentioned, the simulation data were experimentally validated in the papers [29,30]. In table 1 the data from the experiments are presented (from the two mentioned papers) and those extracted from the simulation for the variation of the force with respect to the piston stroke for the two presses.

Were plotted the force variation curves with the piston displacement, and the experimental results and simulation data were also correlated for the two stationary presses with different mathematical functions to determine which mathematical function correlates the most better the pressing process of each of the two stationary presses analysed (fig. 6 and 7).

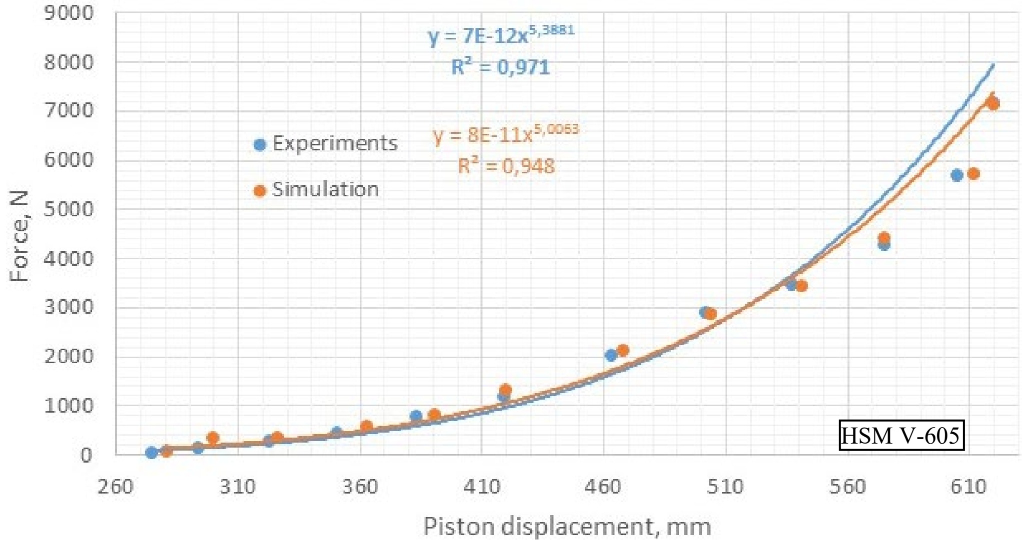

Fig. 6. Variation of force with piston displacement at HSM V-605 press

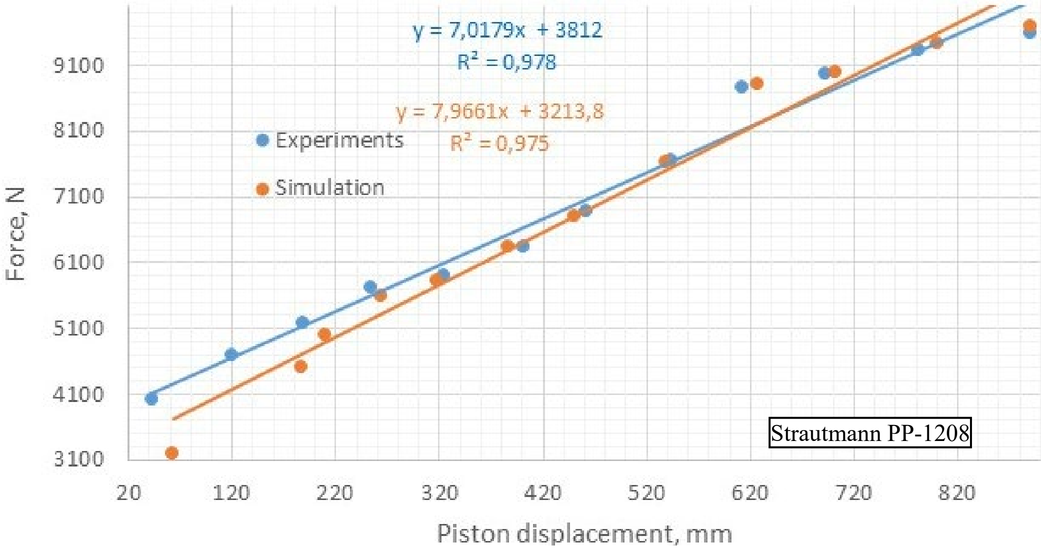

Fig. 7. Variation of force with piston displacement at Strautmann PP-1208 press

From fig. 6 it can be observed that for the HSM V-605 press the data is best represented by an exponential law, reaching values of the correlation coefficient (R^2) of 0.971 for experimental data and 0.948 for simulation data. At the same time to the Strautmann PP-1208 press (fig. 7) the mathematical law that best represents the data is the linear function, obtaining values of the correlation coefficient of 0.978 for the experimental data and 0.975 for the simulation data.

4. Conclusions

For HSM V-605 the maximum force was calculated in the simulation with an error of 0.53% compared to the actual maximum force, and for the Strautmann PP-1208 press the maximum force was calculated in the simulation with an error of 1.15% compared to the maximum actual force. It can thus be said that modelling and simulation can be used with confidence in FluidSIM software for hydraulic systems.

The mathematical laws that best describe the compaction process for the two presses have been determined: an exponential law for the HSM V-605 press (R^2>0.948) and a linear law for the Strautmann PP-1208 press (R^2>0.975).

In addition, based on all that has been presented so far, it can be said with a high level of confidence that the profile of the hydraulic oil pressure variation curve at the Strautmann PP-1208 press corresponds to a linear law on both piston strokes, and to the HSM V-605 corresponds to an exponential law on the stroke of the rod in the cylinder (when pressed) and a logarithmic law on the stroke of the rod in the cylinder.

The efficiency of using the digital simulator depends on a complete databasis of experimental results obtained for different kind of materials.

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