APPLICATION OF 3D PRINTING TECHNOLOGY FOR THE DESIGN AND MANUFACTURE OF SOME COMPONENT PARTS OF SPRAYING MACHINE WITH SOLUTION RECOVERY
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APLICAREA TEHNOLOGIEI DE IMPRIMARE 3D PENTRU PROIECTAREA ȘI FABRICAREA UNOR PĂRȚI COMPONENTE ALE MAȘINII DE STROPIT CU RECUPERARE DE SOLUȚIE

Eugen MARIN [1)], Gabriel-Valentin GHEORGHE [1)], Carmen BĂLȚATU [1)], Marinela MATEESCU [1)]
National Institute of Research-Development for Machines and Installa tions Designed to Agriculture and Food Industry - INMA, 6 Ion Ionescu de la Brad Blvd., Bucharest / Romania
Tel: +040760746566; E-mail: carmen.vasilachi@gmail.com
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ABSTRACT
The paper presents the design process of a Venturi injector, by checking and choosing a type of material with physical-mechanical properties necessary to obtain the best possible results during the work process. The injector is part of the solution recovery system from the vineyard spraying machine and was made with the FDM manufacturing technology by selectively depositing of molten material in a predetermined path, layer by layer. Materials used were ABSpro™, MagicFil™ Thermo PLA and Onyx. The presented results allow useful recommendations for the making of other components of agricultural machines using 3D modeling and printing technology.

REZUMAT
Lucrarea prezintă procesul de proiectare a unui injector Venturi, prin verificarea și alegerea unui tip de material cu proprietăți fizico-mecanice necesare obținerii unor rezultate cât mai bune în procesului de lucru. Injectorul face parte din sistemul de recuperare a soluției de la mașina de stropit plantații viticole și a fost realizat cu tehnologia de fabricare FDM prin depunerea selectivă a materialului topit într-o cale prestabilită, strat după strat. Materialele utilizate au fost ABSpro™, MagicFil ™ Thermo PLA și Onyx. Rezultatele prezentate permite recomandări utile pentru realizarea și a altor componente ale mașinilor agricole folosindu-se de tehnologia de modelare și imprimare 3D.

INTRODUCTION
The most important factors resulting from agricultural activities that have a large proportion in environmental pollution are those produced by the application of plant protection technologies with chemical products (pesticides), aiming to combat diseases, insects, rodents, nematodes and weeds in agricultural crops and tree-vine plantations (*Tabarasu et al., 2021*).

Application of the Council Regulation (EC) no. 834/2007 of 28 June 28 2007, related to organic production and labeling of organic products, led to a major change in viticultural practices, as it required the replacement of chemical pesticides based on copper and sulfur with organic ones, which led to the realization of spraying machines that use the control products more efficiently and to develop ecological strategies for agriculture (*Merot et al., 2020*).

At the same time, Directive 2009/128/EC of the European Parliament and of the Council established a framework for Community action to achieve the sustainable use of pesticides encouraged the replacement of chemical means for the effective management of pests and diseases with biological products (*Doley et al., 2019*).

In these circumstances and due to the objectives of the European Green Pact regarding the reduction, by 2030, of GHG, by 50-55% compared to the levels of 1990, and carbon neutrality by 2050 (*Claeys et al., 2019; Sikora et. al., 2021*), different companies have developed spraying machines for vine plantations that are equipped with a spraying system with panels placed on either side of the row, through which the solution is sprayed from opposite sides, achieving a complete and efficient treatment, and the excess substances drip on these panels to the bottom, from where they are recovered and transferred back to the tank without losing a large amount of solution to the atmosphere or to the ground.

Such companies are: LIPCO GmbH from Germany (*Holthusen et. al., 2019*), CLEMENS from Germany (*Rieger, 2017*), GREGOIRE from France (*Nitu et. al., 2018*), BERTONI from Italy (*Losavio, 2011; Sarri et. al., 2014*), etc.

All these spraying machines use pesticide recovery panels located on either side of the vine row and incorporate a recovery system that uses a recirculation pump.

At INMA Bucharest, a spraying machine was made that uses vacuum injection for the recovery of the solution based on the principle of the Venturi tube, and the component is called "Venturi injector". The Venturi type injector is based on the "Venturi effect" operating principle, according to which, when a pressurized liquid flows through a given section, with sudden narrowing and progressive expansion, the phenomenon of suction occurs (*Figueras Segalà, 2017*).

The Venturi injector has simple construction, high reliability in operation and can be made with the help of rapid prototyping technology (*Gardan, 2017*), which in recent years has become an extremely useful tool in the construction industry of agricultural machinery.

Currently, the Venturi injector is widely used in the fertigation system for the purpose of administering liquid chemical fertilizers, together with water distributed to agricultural crops *(Huang, 2008; Marin et al., 2014; Șovăială et al., 2019*).

The technical issue that the authors propose in this paper is the use of the Venturi injector, which was made by 3D modeling and printing technology, in the technological cycle of treating vine plantations with the recovery of the working liquid. For this purpose, the research carried out for the verification and selection of a type of material from which the Venturi injector is made, which allows performing the working process in optimal conditions, is presented.

MATERIALS AND METHODS

The three-dimensional geometric model of the Venturi injector (Fig. 1) was developed using the SolidWorks software, which is a package of three-dimensional (3D) geometric modeling programs produced by SolidWorks Corporation in the United States (*Deepak and Lakshmanan, 2020*). For the research carried out as part of the work on the Venturi injector, the inlet diameter is d_1=20 mm, the diameter of the suction pipe is d_2=10 mm, the inlet and outlet slope of the throttling zone is 17.5° and 4° respectively, the diameter of the strangulation zone is D=4 mm, and its length is L=27 mm. Suction is made through a slot located at the top of the suction pipe and has a diameter of D_a=17 mm.

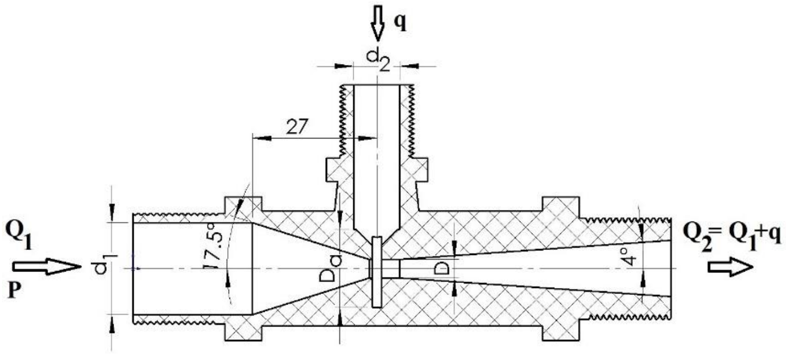


Fig. 1 – Schematic diagram of the Venturi injector

L is the throat length; D is the throat diameter; D_a is the slot diameter; d_1, d_2 are the inlet diameter and suction pipe diameter, respectively; P is the inlet water pressure; Q_1, Q_2, q are the discharges from inlet, outlet, suction part, respectively

The SolidWorks Flow Simulation application (*Verma, 2018*), which uses CFD (Computational Fluid Dynamics) analysis, allowed fast and efficient simulation of fluid flow through the Venturi injector to determine its performance.

In order to verify and choose a certain type of material for the Venturi injector, it was used a rapid prototyping technology using 3D printers, Markforged Onyx One by Fused Filament Fabrication (FFF), one of the most popular additive manufacturing (AM) processes using thermoplastic polymers (Singh et. al., 2020) from Onyx Carbon Fiber Filament specially developed by Markforged, based on nylon reinforced with carbon flakes (*Marin et. al., 2021*) and very cheap UP BOX (*Dabadi et al., 2021*), through Fused Deposition Modeling (FDM), which is one of the most used 3D printing technologies (*Rahim et. al., 2019*), with filaments of thermoplastic materials of acrylonitrile-butadiene-styrene (ABSpro™) and polylactic acid (MagicFil™ Thermo PLA).

The filaments for the 3D printing of the Venturi injector were commercially purchased from thermoplastic materials, and their characteristics are shown in Table 1.

Table 1

Characteristics of the materials used for 3D printing of the Venturi injector

Characteristics of materials	ABSpro™	MagicFil ™ Thermo PLA	Onyx
Diameter, mm	1.75	1.75	1.75
Specific gravity, g/cm^3	1.02	1.24	1.2
Melt flow rate, cm^3/10min	5.5	6.0	4.0
Impact strength, KJ/m^2	39	7.5	30
Tensile strength, MPa	39.9	110	36
Tensile modulus, MPa	2100	3310	2900
Elongation at break, %	11	9.2	14
Print temperature, °C	± 245 - 275	± 180 - 220	± 240 - 245
Melting temperature, °C	± 252 ± 10°	± 210 ± 10	± 242 ± 10

The manufacturing steps of the Venturi injector by rapid prototyping were:

- the generation of CAD files - which was made by using SolidWorks 2018 assisted design program. Figure 2 shows a section through the 3D geometric model of the Venturi injector made by means of the SolidWorks 2018 software.

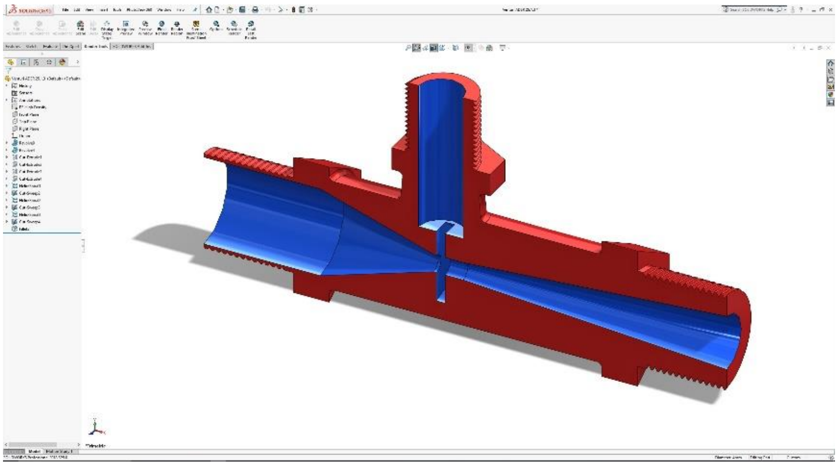


Fig. 2 – Section through the geometric 3D CAD model of the Venturi injector

- conversion of component files in STL format - the Standard Triangulation Language - Stereolithography format is a standardized format that approximates the three-dimensional surface of any object by means of a set of plane triangles; the information corresponding to each triangle consists of the coordinates of the three vertices and the direction of the external normal. The degree of approximation of the geometry depended on the density of the triangular network, the precision increasing with the number of triangles. In SolidWorks 2018, exporting the geometry in STL format was done by selecting the "Save as" option and specifying the export options, through the Export Options window (Fig. 3);

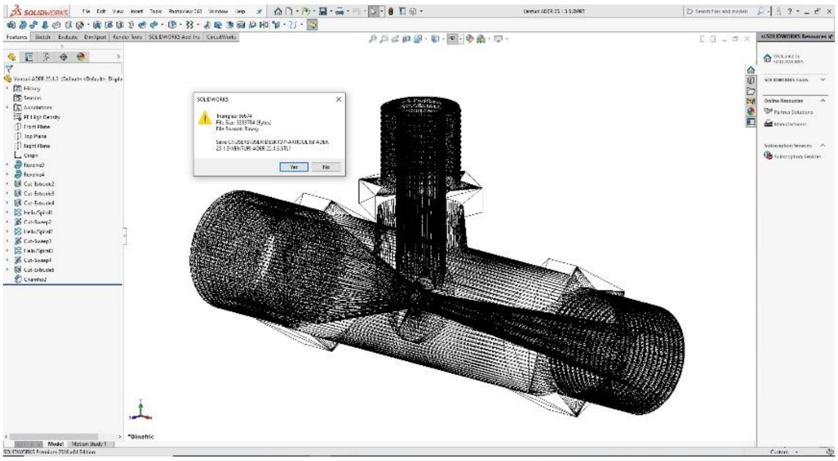
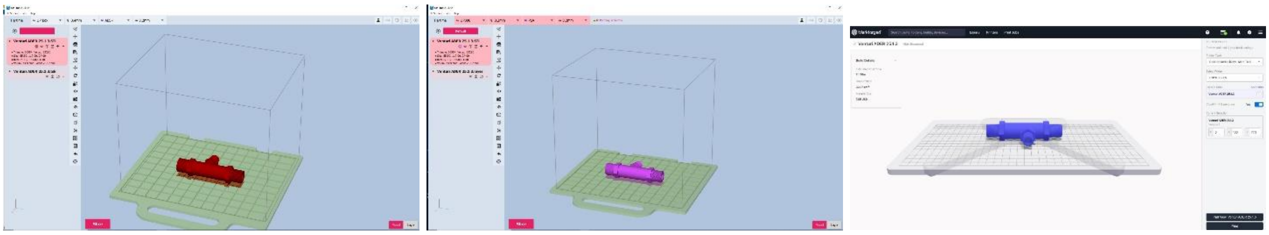


Fig. 3 – Saving the geometry of Venturi injector in STL format

- the decomposition of the object into layers for the three types of thermoplastic materials that was made in the specialized programs Cloud Eiger Software provided by the printer supplier Markforged Onyx One and UP Studio 2 provided by UP BOX, the printer supplier (Fig. 4);



a) b) c)

Fig. 4 – Decomposition of the Venturi injector into layers for the three types of thermoplastics
a) ABSpro™; b) MagicFil ™ Thermo PLA; c) Onyx

- printing of the 3D object, layer by layer;
- extracting the object from the printer and removing the support material.

The characteristics of the Markforged Onyx One printer (Fig. 5) are: layer thickness (in the Z direction): resolution: 400 microns; maximum printing dimensions (X×Y×Z), mm: 255×205×205; overall dimensions, cm: 57.5×32.2×36.6. The features of the UP BOX printer (Fig. 6) are: resolution: 100 microns; maximum printing dimensions (X×Y×Z), mm: 320×132×154; overall dimensions, cm: 48.5×52×49.5.

Fig. 5 – Markforged Onyx One Printer

Fig. 6 – UP BOX Printer

RESULTS

To achieve the fluid flow simulations, three injectors were manufactured by 3D printing from the following thermoplastic materials: ABSpro™, MagicFil™ Thermo PLA and Onyx. Following the 3D printing manufacturing process, the Venturi injector was first cleaned of the support material and then checked for dimensional accuracy.

The dimensional accuracy of the three injectors made was measured after 3D printing with an electronic caliper and it was found that there are no significant differences between the dimensions measured compared to the dimensions in the execution drawing.

Figure 7 shows the three injectors manufactured by 3D printing from three types of thermoplastic materials.

a) b) c)

Fig. 7 – Venturi injector obtained by 3D printing from three types of thermoplastic materials
a) ABSpro™; b) MagicFil ™ Thermo PLA; c) Onyx

Simulations with the SolidWorks Flow Simulation application allowed the analysis of a wide range of complex problems - working pressures and fluid forces, which can be critical.

Figure 8 shows a sequence after running the simulation, for the pressure and flow rate of the working fluid through the Venturi injector.

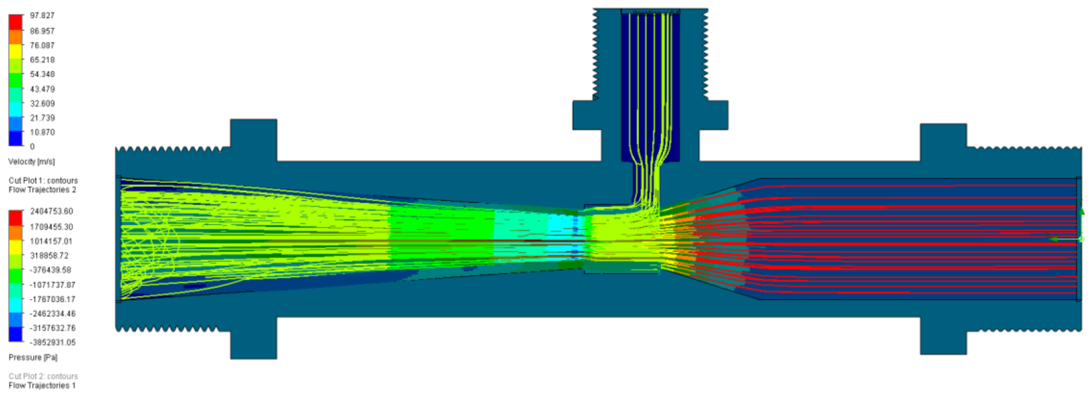


Fig. 8 – Sequence after the CFD run for the pressure and velocity of the water flow through the Venturi injector

As shown in Figure 9, the pressure is high at the beginning of the Venturi injector section, where the inlet diameter is d_1=20 mm, it starts to decrease in the convergent section with the inlet slope of 17.5°, there is a sudden decrease in the throttling zone with diameter D=4 mm due to friction and starts to increase because part of the pressure is recovered in the diffuser by converting kinetic energy into pressure energy as an effect of slowing down the speed of the working fluid, and the maximum pressure value in the injector being 2404753.6 Pa.

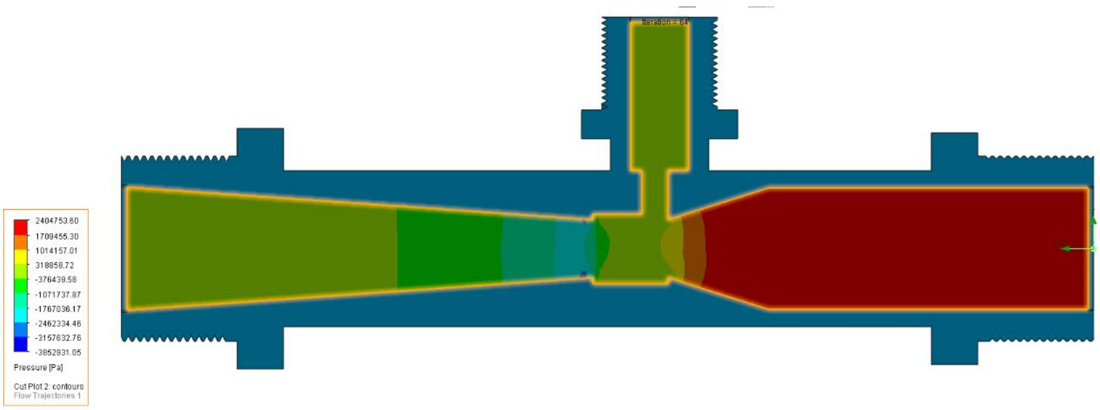


Fig. 9 –Sequence of the working fluid pressure magnitude contour

Figure 10 shows a sudden increase in the speed of the working fluid in the choke area, where it had a maximum value of 94.72 m/s, followed by a decrease in the diffuser area.

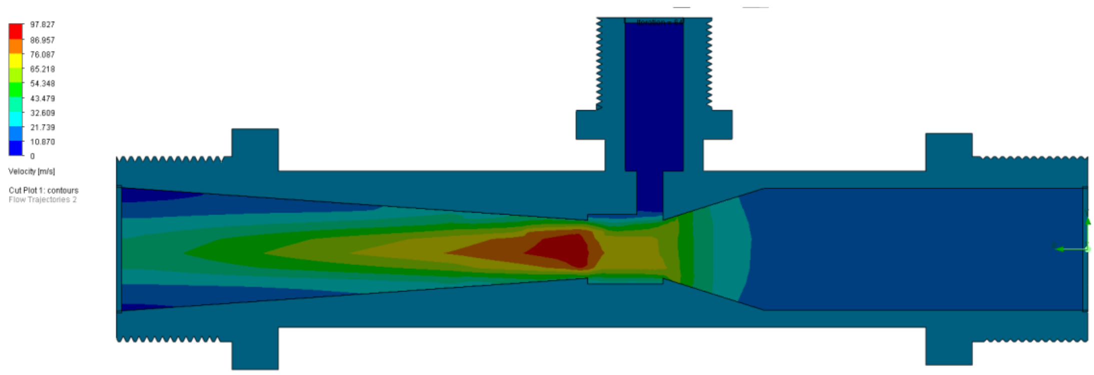


Fig. 10 – Sequence of the working fluid velocity magnitude contour

Verification with the SolidWorks Simulation application on the mechanical behavior led to the choice of a type of material that would allow the work process to be ensured in optimal conditions, which involved importing the geometry of the created model, defining the materials, defining the appropriate restrictions for the discretizations, running the program to calculate analysis of Von Mises stress, displacement, relative elongation and visualization of the results in the form of diagrams.

Table 2 shows the results after running the analysis study for the calculation of Von Mises stress, displacement, relative elongation, which was based on geometry, material, load, constraint conditions and discretization type.

Table 2

Results obtained from the mechanical verification of the Venturi injector

Name	Type	Min	Max
ABSpro™			
Stress1	VON: von Mises Stress	0.2541 kN/m^2	15.58 kN/m^2
Displacement	URES: Resultant Displacement	0 mm	0.03016 mm
Strain1	ESTRN: Equivalent Strain	0 mm	0.004643 mm
MagicFil ™ Thermo PLA			
Stress1	VON: von Mises Stress	0.2242 kN/m^2	16.58 kN/m^2
Displacement	URES: Resultant Displacement	0 mm	0.04275 mm
Strain1	ESTRN: Equivalent Strain	0 mm	0,006558 mm
Onyx			
Stress1	VON: von Mises Stress	0.2398 kN/m^2	16.05 kN/m^2
Displacement	URES: Resultant Displacement	0 mm	0.03031 mm
Strain1	ESTRN: Equivalent Strain	0 mm	0.004684 mm

In Figure 11, the Von Mises stresses obtained after running the analysis study of the three types of materials are graphically represented.

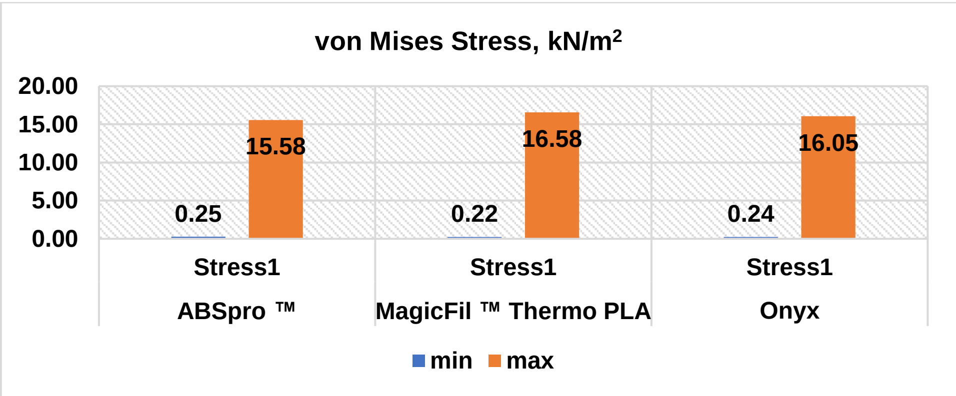


Fig. 11 – Graphic representation of the Von Mises stresses obtained from the analysis of the three types of materials

Figure 12 presents the displacements obtained after running the analysis study of the three types of materials.

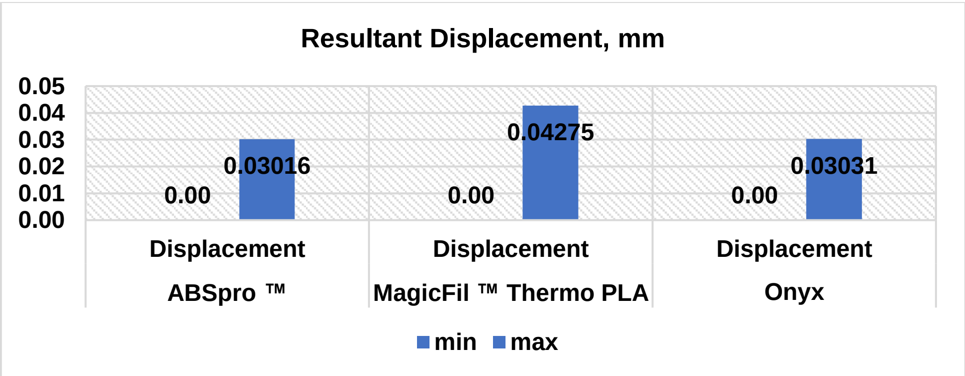


Fig. 12 – Graphic representation of the displacements obtained from the analysis of the three types of materials

In Figure 13, the relative strains obtained after running the analysis study of the three types of materials are graphically represented.

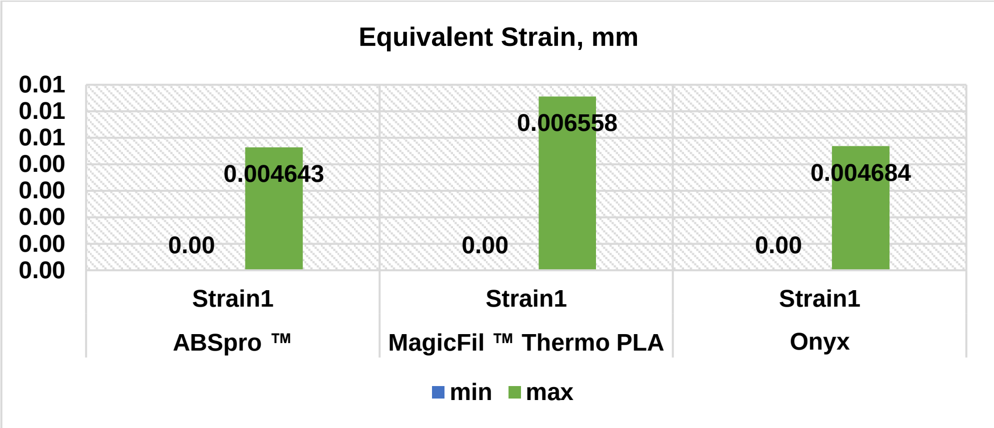


Fig. 13 – Graphic representation of the relative strain obtained from the analysis of the three types of materials

The comparison of these indicators led to the choice of the optimal variant, namely ABSpro^{TM}, a very robust material from a structural point of view.

The experimental part aimed to confirm that the Venturi injector manufactured by 3D printing withstands and works at a maximum system working pressure of 25 bar. This was fitted to the hydraulic system of the spraying machine with solution recovery, where the part of the liquid that had dripped on the panels and reached the storage tanks located at the bottom of the panels was recovered by means of Venturi injectors and sent to the liquid tank for reuse.

Figure 14 shows some aspects during the experimentation of the vineyard spraying machine for the verification of the Venturi injector solution recovery system.

Fig. 14 – Testing the spraying machine with solution recovery system equipped with Venturi injectors

Following an analysis based on the fluid flow, it was concluded that for the solution recovery system from the vineyard spraying machine, Venturi injectors made with FDM technology through 3D printing from the ABSpro^{TM} material can be used, which ensures performing the working process in optimal conditions.

CONCLUSIONS

- By means of 3D printing technology, the Venturi injector could be manufactured, according to the execution drawing, very quickly and at low cost;
- Fluid flow simulations and checks on mechanical behavior were able to determine that the Venturi injector made with FDM technology by 3D printing from ABSpro^{TM} material provides optimal conditions for performing the working process in the working solution recovery system from vineyard spraying machines;
- After testing on the vineyard spraying machine it was found that the Venturi injector withstood the maximum working pressure without cracking and without visible damage;
- The results of the research presented in the paper allow useful recommendations for making other components of agricultural machines using the 3D modeling and printing technology.

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