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ANALYZING THE ASPECTS RELATED TO THERMAL TRANSFER IN THE ADDITIVE MANUFACTURING PROCESS BY THERMOPLASTICS USING PLA AND RESPECTIVELY ABS FOR EXTRUSION.

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ABSTRACT: The study carried out aims to determine the way in which the heat transfer occurs from the front part of the orifice of the extrusion nozzle of the thermoplastic material to the component elements of such an assembly. The paper considers the study in the introductory part of the current situation in the specialized literature. The second part is affected by the analysis of their geometric and dimensional structure and the way of their realization and their interconnection. Further, in the analysis, the way in which the discretization of the process of calculating the temperature values is carried out in the simulation program was considered, and last but not least, the way of its evolution. Based on the graphic simulation for the extrusion temperatures considering poly lactic acid (PLA) and respectively acrylonitrile butadiene styrene (ABS) it was possible to highlight that the area where the extruded material in the part of the structure modification has an increasing temperature trend towards the upper part of cooling it.
KEYWORDS: 3D printing; additive manufacturing; fuse deposition modelling; heat transfer; thermal simulation

1. INTRODUCTION (HEADING 1)

The technology of rapid prototyping (rapid printing) has been developed since the end of 1980 thus improving the manufacturing process of the high-quality finished components. Fused Deposition Modelling (FDM) can be a fast-printing technology widely used due it is flexibility of the process in the industry [1,2].

In the traditional manufacturing process (cutting processing, assembly processing and welding process), the processing costs of the raw materials are higher both in terms of material losses and in terms of energy consumption, compared to the processes of additive manufacturing of the same types of finished products.

FDM type printers ensures a lower manufacturing costs both from an energy point of view and from the point of view of material consumption used to make finished products, thus motivating the development of 3D printing through professional and open-source versions. However, the professional and or open-source 3D printing system and process should be investigated very carefully, especially on the liquefied side to observe the material flow and thermal behaviour inside the liquefied [3,4].

Professional printing represents the additive manufacturing system where the process is thermally controlled at the level of the laminating system or assembly of the material used for manufacturing as well as at the level of the printing surface and the space where the printing takes place [5].

The open-source variants [11] are also usually found under the term printers, or printers with low manufacturing costs, in which the control of the space in which the printing is carried out is neglected. This will lead us in this article and in future experimental trials to consider the use of a cooling source of the wire heating assembly that is supplied with air from the ambient temperature and not with air from inside the thermally controlled enclosure, which at the open-source solution is not required. Also, the professional solution for the efficiency of the drive motor for the translation movement of the thread or the granular particles will be provided with a cooling part from the ambient air.

The process of fused deposition (FDM) is initiated when the thermoplastic material type like a filament is fed into the liquefaction block and pushed by a motor and to be plasticized, then the material is extruded through a nozzle with a specific geometry and solidified by process layer by layer until the manufacturing process is complete [6,7].

The 3D printing techniques with fused filament fabrication (FFF) this process consists of heating a granular plastic material (thermoplastic polymer thread) of PLA, ABS or other thermoplastic polymer type and extruding it through a nozzle with a preset geometry through the layer-by-layer process of the object to be printed [8-10].

The advantages of fast printing refer to the fact that: 3D printing technology is cheap and accessible, easy to make, and the production process is very fast.

An extremely important element of the printer is the quality of the extruded, as it takes the wire from the spool, melts it, and then deposits it on the print surface according to the print parameters the printer will read from the console [12-14].

The optimum temperature that represents our parameter of interest should be between 180-220 ^{o}C for PLA and between 230 to 260 ^{o}C for ABS.

2. CONSTRUCTIVE CONSIDERATIONS ON THE ACHIEVEMENTS OF THE EXTRUDER ASSEMBLY USED IN THE EXPERIMENTAL RESEARCH PROGRAM.

The main component elements of the assembly are the following:

2.1 Heating block constructive consideration

The heating block, this has the role of heating the wire up to the liquefaction point of the plastic and on it will be mounted a nozzle with a specific geometry, the thermal tube for separating the threaded resistance and the thermistor Figure 1.

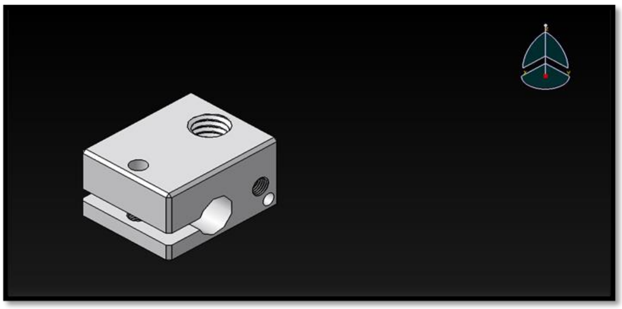

Figure 1. Heating block

The heating block can be made both by casting and then using the manufacturing technology using the processing machines, you can turn or milling machines more precisely in the area where the resistance that heats the block must be clamped, as well as the use of drilling machines for the housing of the temperature sensor (thermistor) at the same time the tap will be used to create the threaded part. The material used for the heating block is aluminium because it has a much higher thermal conductivity.

2.2 Print head constructive consideration

The nozzle or print head has the role of taking the liquefied material and extruding it on a platform through different translational movements both in the horizontal and vertical directions in the form of layers, it being mounted by threading in the hot block (tightening medium but not at maximum in order not to damage the nozzle thread or the thread of the hot block, it is recommended to leave a space of 0.2 mm between the hexagonal part of the print head and the hot block) Figure 2.

The nozzle or printing head can be made with cutting tools (lathe machine, milling cutters) as well as with drilling tools. The recommended material for common thermoplastic materials is brass because it has much higher thermal properties compared to other metals, being at the same time extremely malleable and subject to the risk of crushing the thread when it is mounted in the hot block. For materials recommended for the engineering field with high mechanical properties, it is recommended that the nozzle be made of treated stainless steel or high alloy steel.

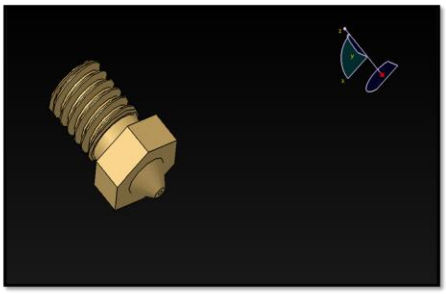

Figure 2. Nozzle/Print head with specific geometry

2.3 Threaded thermal separation tube constructive consideration.

The threaded separation thermal tube has the role of heating the solid material to a certain melting point and which is mounted in the heating block, it must be tightened by threading until the point of perfect contact between the nozzle and the tube so that there is no space inside the hot block because if there is space the liquefied material will not pass properly into the print head sector, the material hardening. Another very important aspect is the fact that before threading the thermal tube into the hot block, a thermal paste must be applied to the threaded portion into the hot block for a better thermal conduction Figure 3.

This element can be made by cutting with a lathe machine and after, using the drilling machines. The material used can be steel or other alloy material. Currently, there are bimetal constructive solutions where the inner and lower part of this tube is made of steel and the upper and outer part of the tube is made of brass or copper to increase heat transfer.

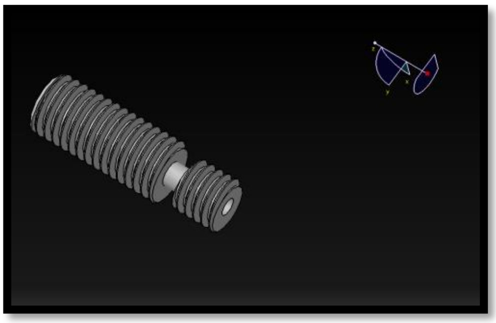

Figure 3. Threaded thermal separation tube.

2.4 Thermal radiator constructive consideration

The thermal radiator (cooling block) has the role to maintain a constant temperature at a certain level, being mounted over the thermal tube and at a certain distance from the heating block, and it is cooled (thermal controlled) by a fan (cooler) attached to the plastic support Figure 4.

The cooling block can be made by both machining and casting. Here you can use either the lathe or the CNC type machines or the milling machines. At the same time, the drilling process will be used (with drilling machines for the part of the holes), being a heat dissipator, it will be assigned a material that has the best possible thermal properties to achieve optimal cooling through heat dissipation, the material it can be aluminium, since it is not required mechanically.

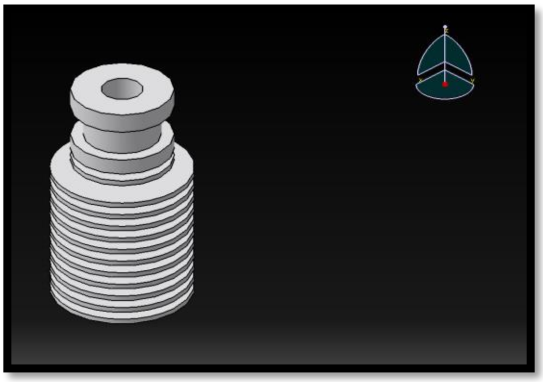

Figure 4. Thermal radiator (cooling block)

2.5 Bracket support holder for the ventilator constructive consideration.

The holding support for cooling the radiator has the role of supporting the thermal radiator in a fixed position, on which the fan is mounted. At the same time, this support is made of plastic so that it is not heavy and not made of metal, so as not to load the printing arm of the machine Figure 5.

Figure 5. Bracket support holder for the ventilator

2.6 Cooling fan constructive consideration.

The cooling fan has the role of introducing technical air from the ambient environment to cool the thermal radiator (cooling block), and it is mounted on the support and supplied with a current of 12- or 24-volts Figure 6.

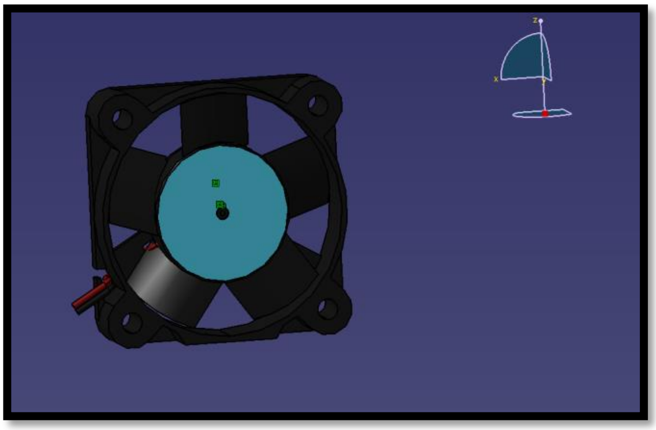

Figure 6. Cooling fan

2.7 Assembling constructive consideration.

The following elements will be inserted into the heating block: The thermal resistance R [W/m2K] that will heat the hot block and the thermistor that will measure the temperature in different areas of the assembly, being on the temperature sensor side [K] Figure 7.

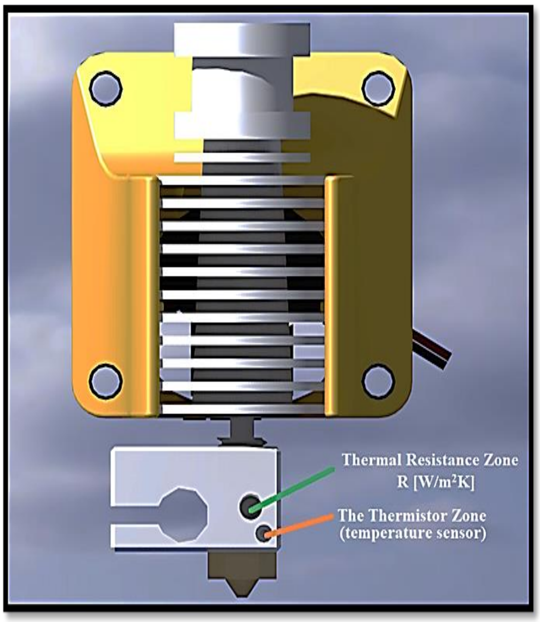

Figure 7. The housing of the thermal resistance and the temperature sensor

The temperature can be very well optimized in this sense by the thermal radiator ventilated with air and measured with the help of temperature sensors that are located on different areas of the assembly. At the same time, the thermistors will be placed both in the cooling block (thermal radiator cooled by ventilation) and in the hot block (heating area of the wire to be melted) Figure 8.

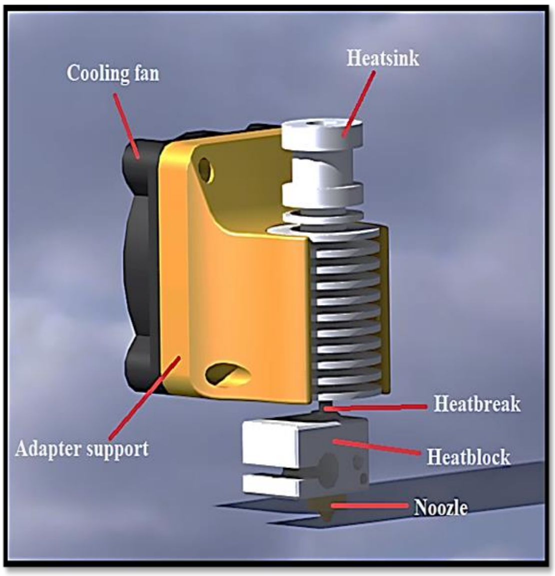

Figure 8. Assembling structure

3. THE STUDY OF THERMAL TRANSFER IN THE STRUCTURE OF THE MATERIAL EXTRUSION ASSEMBLY.

Constructive considerations on how to organize an experimental study using the components mentioned in chapter 2 by mounting them.

For the experimental study part, the component parts related to the assembly were used, they were created in the 3D modelling program Dassault Systems CATIA V5, and then these parts were imported into the Autodesk Inventor 2024 simulation program for the assembly part and then the entire assembly has been exported and prepared for import into the Autodesk CFD 2024 Educational simulation program.

The author's interest was to simulate in two hypotheses, the temperature part for PLA T=210 °C and for ABS T=240 °C (the previous values or considered at the exit surface of the nozzle) and to observe their temperature gradient.

3.1 Simulation 1 PLA T=210 °C

In the first step of this study, it is put the assembly created with the Inventor program in the interface CFD of Autodesk educational interface which are selected from the program menu Figure 9.

After the first step was access the simulation program tree (left side) is done on the left side at the Design study bar, then we will enter the temperature parameters on the boundary conditions side, the assignment of material to the main components as well as the discretization of the mesh with the value of 1 for the entire assembly design Figure 10.

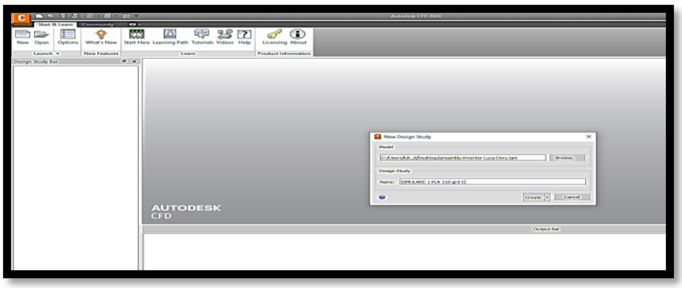

Figure 9. Introduction of the 3D model in Inventor CFD

Figure 10. Optimization of the parameters in the tree of the Inventor CFD simulation program

Next step is the assignment of the materials for each individual element from the 3D model Figure 11:

- the nozzle or print-head has been assigned brass-based material,
- the hot block received aluminium 6061 as material,
- the threaded thermal tube received C45 steel as material,
- the cooling block (thermal radiator) received aluminium 6061 as material,

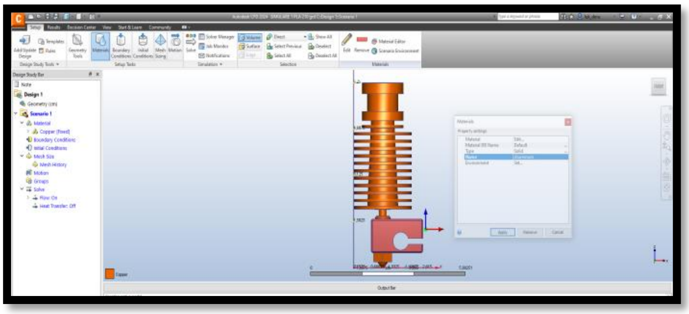

Figure 11. Assigning material to each individual element of the 3D model

An important step is the application of the boundary conditions for the radiator rings with a temperature of 25 °C considering the temperature of the environment to which the whole assembly is exposed. The application of temperature was done both on the lower part of the rings and on the superior zone of the cooling block Figure 12.

The temperature assignment for the print-head (nozzle) at the value T=210 °C for the PLA case, selecting all the surfaces of the part exposed to the outside. This condition is important and represent the important parameter which will help us find the temperature on the orifice with resistance Figure 13 and next are assignment of the mesh with the value of 1 on the entire assembly design to validate the data to be simulated by obtaining the temperature gradient diagram Figure 14.

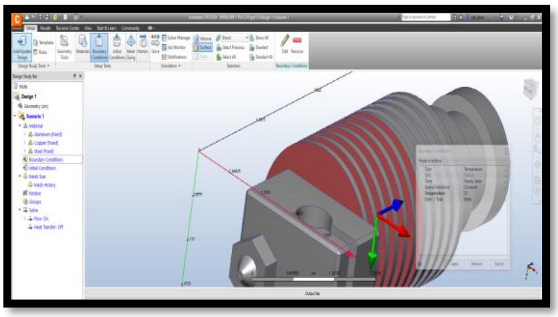

Figure 12. Application of the temperature T=25 °C on the lower and upper rings of the thermal radiator

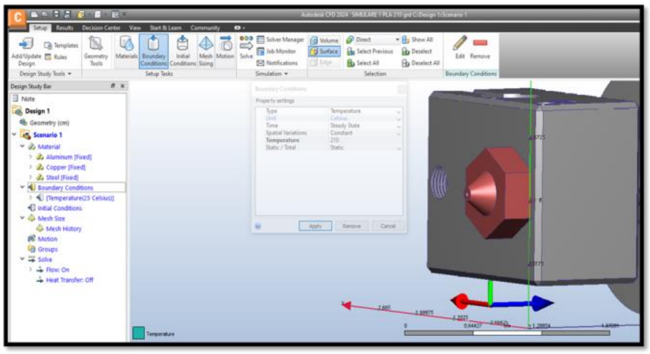

Figure 13. Application of the temperature value T=210 °C on the print head (PLA simulation)

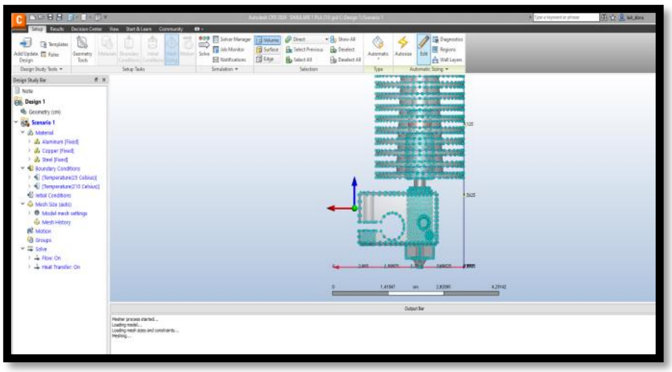

Figure 14. Mesh assignment with the value of 1 on the entire assembly design

After applying the mesh, it is necessary to access the solving part of the Inventor CFD 2024 Educational simulation program menu, by pressing the solve button and selecting a precision calculation with 100 iterations to obtain the temperature gradient diagram. At the same time the period of determination (time) of the heat transfer from the hot source to the component elements is a slow process which is why it is not recommended to sample the simulation with a frequency lower than a few hundreds or thousands of seconds Figure 15.

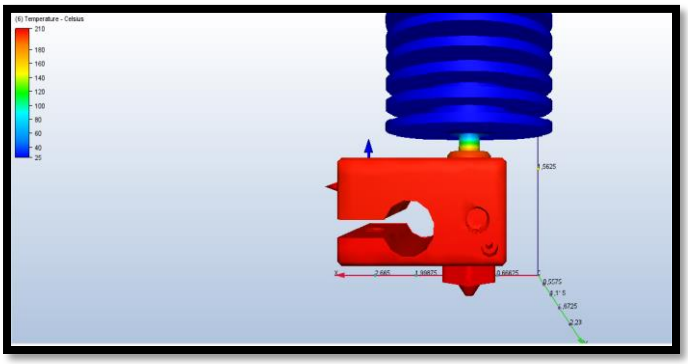

Figure 15. Temperature gradient for PLA with T=210 °C (temperature diagram)

3.2 Simulation 2 ABS T=240 °C

The same simulation process was done in the case of secondary simulation, but in this case the temperature for the print-head (nozzle) was 240 °C, all the parts of the part exposed to the environment being selected, and then the temperature gradient on the hole was to be simulated with resistance. Figure 16.

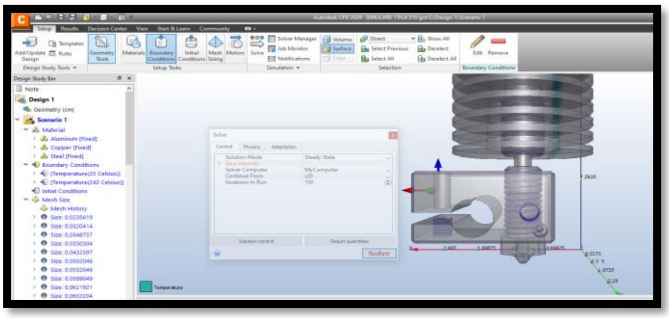

Figure 16. Application of the temperature value T=240 °C on the print head (ABS simulation)

Similar was proceed in the second case for a temperature value of T=240 °C in the print-head area and with the respected mesh value of 1, the solution part from the menu of the Inventor CFD 2024 Educational simulation program was used, pressing the solve button and selecting 100 iterations at the calculated value to obtain the temperature diagram (temperature gradient) Figure 17.

4. CONCLUSION

Considering that the connection and validation of the data from the simulation will be done on a real experimental stand where the positioning distances of the transducers for measuring the temperature, usually thermistors, have a value of the order of millimetres, the accuracy of the simulation and determination of the temperature variation must not be below a value of the order of millimetres, which is why I chose a mesh value of 1.

It can be seen from the analysis of the results in Figure 15 and respectively Figure 17 that there are differences in evolution in the narrow area of the metal tube. We are entitled to state that as the extrusion temperature increases, the cold zone at the top evolves in the direction of its reduction towards the top. It should be shown that this evolution is important from two points of view, that of the process of extrusion and deposition of material on the printing surface, but also from the point of view of possible blocking processes of the flow of the material as a result of the increase in the volume of the softened area in relation to the solid area that will push the material.

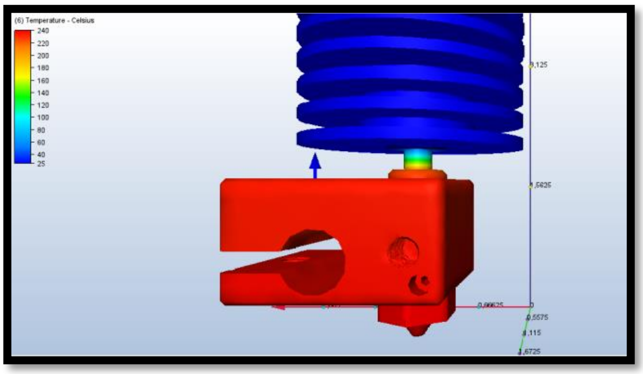

Figure 17. Temperature gradient for ABS with T=240 °C (temperature diagram)

For both simulations, the temperature on the heating block, in the zone of the hole where the electric resistance is going to be mounted, does not show a significant temperature loss, on the contrary it remains high over the entire surface, varying between a minimum of 210 °C and a maximum of 240 °C.

5. REFERENCES

1. Gibson, I.; Rosen, D.W.; Stucker, B. Introduction and basic principles. In Additive Manufacturing Technologies; Springer: Boston, MA, USA, 2010.
2. Snyder, T.J.; Andrews, M.; Weislogel, M.; Moeck, P.; Stone-Sundberg, J.; Birkes, D.; Hoffert, M.P.; Lindeman, A.; Morrill, J.; Fercak, O.; et al. 3D Systems' Technology Overview and New Applications in Manufacturing, Engineering, Science, and Education. 3D Print. Addit. Manuf. 2014, 1, 169–176.
3. Tofail, S.A.M.; Koumoulos, E.P.; Bandyopadhyay, A.; Bose, S.; O'Donoghue, L.; Charitidis, C. Additive manufacturing: Scientific and technological challenges, market uptake and opportunities. Mater. Today 2017, 21, 22–37.
4. ISO 17296-2:2015; Additive Manufacturing—General Principles—Part 2: Overview of Process Categories and Feedstock. International Organization for Standardization: Geneva, Switzerland, 2015.
5. Vasilescu, M.D. (2017). INFLUENCE OF TECHNOLOGICAL PARAMETERS ON THE DIMENSION OF FLAT AND ROUND PARTS GENERATED WITH ABS BY FDM 3D PRINTING. Nonconventional Technologies Review, 21(4). Retrieved from http://revtn.ro/index.php/revtn/article/view/206.
6. VASILESCU, M.D., FLESER, T., Influence of Technological Parametrs on the Dimension of Threaded Parts Generated with PLA Matherial by FDM 3D Printing, Mat. Plast., 55, no. 4, 2018, p. 718-722.
7. Vasilescu, M.D.; Fleser, T. Influence of Technological Parameters on the Dimension of GEAR Parts Generated with PLA Matherial by FDM 3D Printing. Mater. Plast. 2018, 55, 247–251.
8. Vasilescu, M.D. "Technological and Constructive Considerations on the Realization of Components and Parts Using 3D Printing FDM-Type Technology." Hidraulica Magazine, no. 4 (December 2018): 55-62.
9. Algarni, M.; Ghazali, S. Comparative Study of the Sensitivity of PLA, ABS, PEEK, and PETG's Mechanical Properties to FDM Printing Process Parameters. Crystals 2021, 11, 995.
10. Guo, N.; Leu, M.C. Additive manufacturing: Technology, applications and research needs. Front. Mech. Eng. 2013, 8, 215–243.
11. Lanzotti A, Del Giudice DM, Lepore A, Staiano G, Martorelli M. On the geo- metric accuracy of RepRap open-source three-dimensional printer. J Mech Des 2015;137(10):1017031–8.
12. Bellehumeur C, Li L, Sun Q, Gu P. Modeling of bond formation between poly- mer filaments in the fused deposition modeling process. J Manuf Process 2004;6(2):170–8.
13. Bellini A, Güçeri S. Mechanical characterization of parts fabricated using fused deposition modeling. Rapid Prototyping J 2003;9(4):252–64.
14. Sun Q, Rizvi GM, Bellehumeur CT, Gu P. Effect of processing conditions on the bonding quality of FDM polymer filaments. Rapid Prototyping J 2008;14(2):72–80.