Artículos científicos

Modelado de la manufactura aditiva con métodos numéricos: caso de estudio

Modeling of Additive Manufacturing with Numerical Methods: case study

Modelagem de manufatura aditiva com métodos numéricos: estudo de caso

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Resumen

En el presente trabajo se emplea el método numérico de integración de Lagrange para modelar funciones polinómicas obtenidas en el proceso de manufactura aditiva que satisfacen el tiempo de fabricación en impresión 3D para probetas utilizadas en ensayos mecánicos de impacto en materiales plásticos. Una de las características esenciales de los equipos de impresión es trabajar con un archivo cuya geometría se encuentra en tres dimensiones. Con ello, se busca estandarizar el tiempo que conlleva elaborar el espécimen por medio de funciones matemáticas que permiten optimizar el proceso de impresión, controlando diversos parámetros en los equipos de 3D, como lo son la cantidad de relleno, el arreglo, la calidad y el espesor de capa en la deposición del material fundido. Este caso de estudio demuestra una alternativa para modelar matemáticamente procesos de innovación tecnológica y obtener el tiempo de elaboración óptimo que dependerá de los parámetros del equipo de impresión 3D.

Palabras clave: innovación, manufactura aditiva, modelado, impresión 3D, métodos numéricos.

Abstract

In this work, the ~~Lagrangian~~ Lagrange integration numerical method is used to model polynomial functions obtained in the additive manufacturing process that satisfy the manufacturing time in 3D printing for specimens used in mechanical impact tests in plastic materials. One of the essential characteristics of the printing equipment is to work with a file whose geometry is in three dimensions and what is sought is to standardize the time involved in making the specimen by means of mathematical functions that allow optimizing the printing process, controlling various parameters in the 3D equipment; such as the amount of filling, the ~~arrangement~~ pattern, quality and layer thickness in the deposition of the molten material. This case study demonstrates an alternative to mathematically model technological innovation processes and obtain the optimal processing time that will depend on the parameters of the 3D printing equipment.

Keyword: innovation, additive manufacturing, modeling, 3D printing, numerical methods

Resumo

No presente trabalho, o método de integração numérica de Lagrange é utilizado para modelar funções polinomiais obtidas no processo de fabricação aditiva que satisfazem o tempo de fabricação em impressão 3D para corpos de prova utilizados em ensaios de impacto mecânico em materiais plásticos. Uma das características essenciais do equipamento de impressão é trabalhar com um arquivo cuja geometria é tridimensional. Com isso, pretende-se padronizar o tempo de preparação do corpo de prova através de funções matemáticas que permitem otimizar o processo de impressão, controlando diversos parâmetros no equipamento 3D, como a quantidade de preenchimento, a disposição, a qualidade e a espessura da camada. na deposição do material fundido. Este estudo de caso demonstra uma alternativa para modelar matematicamente processos de inovação tecnológica e obter o tempo de processamento ideal que dependerá dos parâmetros do equipamento de impressão 3D.

Palavras-chave: inovação, manufatura aditiva, modelagem, impressão 3D, métodos numéricos.

Introduction

This work shows a real case study (CE) that applies additive manufacturing (AM) modeling with numerical methods (MN) for the production of plastic material parts — acrylonitrile butadiene styrene (ABS) — used for mechanical impact tests. with the Charpy test.

Now, before going into details, it is important to know the following terminologies: a) MA or 3D printing (I3D) is defined as the process where materials are joined to create three-dimensional objects with the help of a computer-assisted drawing program. (CAD), usually layer by layer (Huang, 2015); b) CAD is a *software* that has extensive editing capabilities in the digital drawing of plans, geometric figures and objects in dimensional (2D) or three-dimensional (3D) form (Tomiyama , 2007); and c) the mathematical model (MM) is the design of a single model, implementing the object-oriented algorithms of these methods and evaluating their results (Fuertes, 2016).

MN are techniques through which it is possible to formulate mathematical problems, in such a way that they can be solved using arithmetic operations. There are many types of MN, which share a common characteristic and invariably require tedious arithmetic calculations. However, the development of efficient and fast digital computers facilitated the solution of NM and engineering problems in recent years (Chapra(Chapra and Canale ,Canale, 2007).

The use of I3D, as part of MA, has diverse applications in engineering; However, one of the actions in which there is a disadvantage is in the approximation through the MM. Therefore, the present work is of utmost importance, since MN is proposed as an alternative to improve the processing conditions in a prototype using mathematical functions to validate the system and identify the trends of MM in this area. In this regard, it is necessary to highlight the usual difficulties with approximation methods (Ezquerro, 2012), which lie in using the usual techniques to achieve the approximation of solutions in specific problems, so the quantification of errors.

3D models can be analyzed with MM based on vectors, systems, functions and basic calculation elements with the objective of locating the transformation operations to be executed directly and organized with each MM and the specific variables of each case study (Castilla(Castilla y Ordoñez , 2014). This results in the use of the different numerical analyzes presented by applied engineering.

I3D stands out for being an essential element of learning mathematical and engineering concepts, which is why a wide trend of variables includes numerical analysis. This means that it offers alternatives for understanding fundamental topics in education and research, since it strengthens learning tools (Blasnilo(Blasnilo *et al* ., 2018).

One of the main advantages offered by MNs applicable to CE is the diverse range of methods that are used in all areas of interest in science, which makes them a necessity in analyzes supported by programs and *software*. The results obtained will be more precise, without forgetting that they are approximation processes in problem solving (Chen, 2019). The CE aims to offer one more analysis alternative in AM for processing through I3D.

The methodology details the steps required for the development of this work and obtaining satisfactory results, thereby offering alternative solutions to a particular CE, identifying the optimal function for the deposition of material with the amount of filler and the time of manufacturing.

The initial hypothesis of the CE is that MNs will solve problems that arise in MA modeling when using I3D. The objective of the CE is to solve with the MN tool the problems that arise in MA modeling when using I3D.
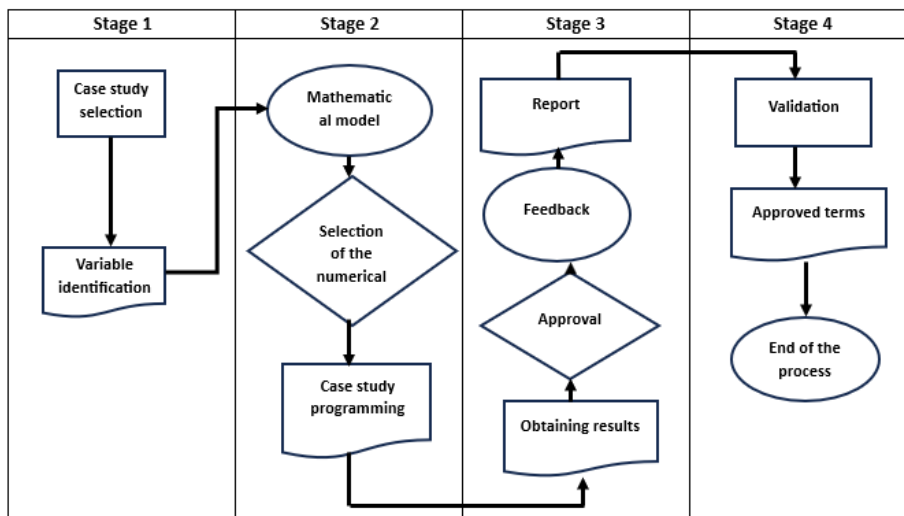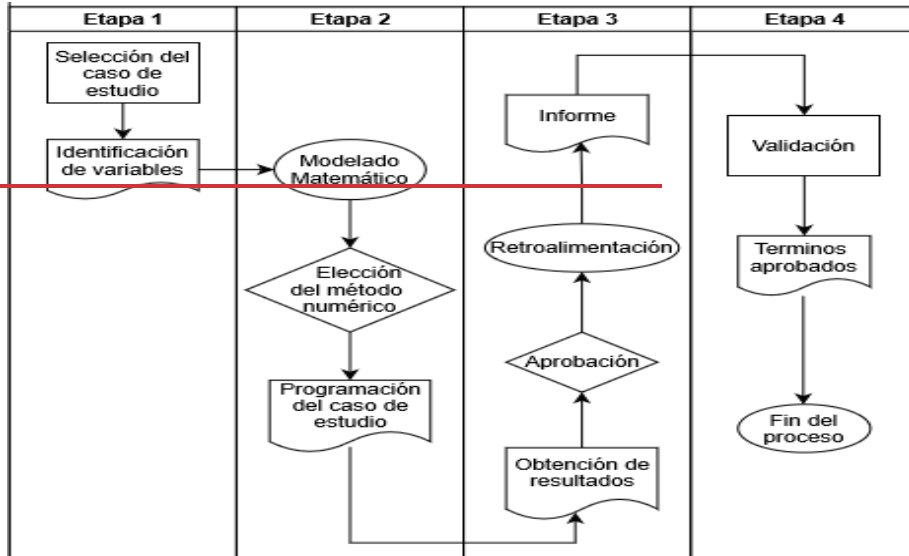
Materials and methods

The materials used to carry out this CE are, in particular, ABS (acrylonitrile butadiene styrene). The methodology was applied in four sequential stages that allowed the CE to be understood in an efficient and detailed manner (figure 1).

Con formato: Español (México)

Figure 1 . Methodology applied to CE

Etapa 1	Etapa 2	Etapa 3	Etapa 4
Selección del caso de estudio	Modelado Matemático	Informe	Validación
Identificación de variables	Elección del método numérico	Retroalimentación	Terminos aprobados
	Programación del caso de estudio	Aprobación	Fin del proceso
		Obtención de resultados	

Stage 1	Stage 2	Stage 3	Stage 4
Case study selection	Mathematical model	Report	Validation
Variable identification	Selection of the numerical	Feedback	Approved terms
	Case study programming	Approval	End of the process
		Obtaining results	

Source: self made

Figure 1 shows the stages in which the work was developed, the interaction between each of them and the continuous feedback in order to maintain the cyclical process of the CE.

The four stages of the work were the following: 1) describes the CE and identifies the variables that must be analyzed, 2) designs the MM according to the CE, selects the MN to occupy and carries out the program in some application programming language, 3) obtains the results of the model with the program, establishes its approval, generates the report of the parameters

considered and provides feedback to the system. Finally, 4) validates the MN, provides the approved terms of the system and finalizes the numerical analysis process of the CE.

Stage 1. Describe the CE and identify the variables to be analyzed

This is classified into two parts: selection of the CE and identification of the variables.

a) The CE selection considered a specimen of test specimens for impact testing in ABS plastic material prepared in I3D to obtain different specimens for analysis and evaluation with MN (figure 2).

Figure 2 . Specimens for impact testing
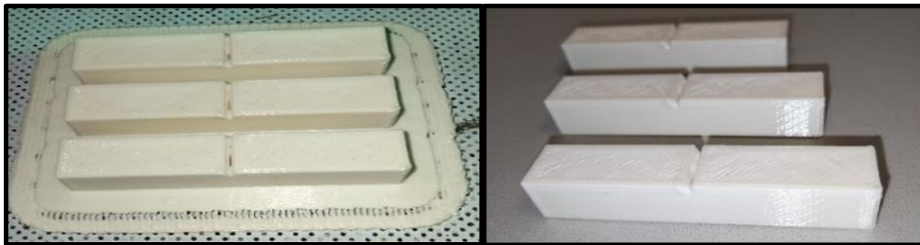
Source: self made

b) The variables identified in the process were the following five: 1) ~~arrangement~~ pattern (Ar), 2) printing quality (Ci), 3) density (D), 4) layer thickness (Ec) and 5) processing time (Te). The above are justified because they generate information on its functionality, improve the specimen process and strengthen the product by making it robust (figure 3).

Figure 3. Variables identified in the CE

(1)   (2)   (3)   (4)

Source: self made

software process in the CE, which have a variation controlled by the user and with this the data is obtained to generate the functions evaluated in this work.

The subsections in Figure 3 mean the order to execute the evaluation of the variables and define (1) the reference of the Ar that are applied to the models that are generated as prototypes in this case study, focused exclusively on PATT.1, (2) the quality selected, from the superficial point of view of the specimen, is what is called normal, (3) the percentage D of the filler used for printing the product ranges from 10% to 100%, and (4) the Ec for material deposition is used from 0.39 to 0.09 mm to create the specimen.

Stage 2. Design the MM according to the CE, select the MN to occupy and carry out the application program

This is classified into three ~~parts :~~parts: a) MM, b) selection of the MN and c) programming of the evaluation case.

a) The MM is the process where data is collected from each simulation with the corresponding variables. They serve as a basis for applying the MNs and for obtaining functions that validate the 3D processing. However, the CE is analyzed and the information is established with the assigned variables (table 1).

Table ~~1~~ 1. Data obtained from experimentation in 3D printer *software*

Consistent print quality and ~~arrangement~~ pattern		Consistent print quality and ~~arrangement~~ pattern		Consistent print quality and ~~arrangement~~ pattern	
Density 10%		Density 30%		Density 50%	
Layer thickness [mm]	time [min]	Layer thickness [mm]	time [min]	Layer thickness [mm]	time [min]
0.39	18	0.39	19	0.39	19
0.29	23	0.29	23	0.29	24
0.19	25	0.19	26	0.19	28
0.14	27	0.14	29	0.14	31
0.09	32	0.09	35	0.09	37
Consistent print quality and ~~arrangement~~ pattern		Consistent print quality and ~~arrangement~~ pattern		Consistent print quality and ~~arrangement~~ pattern	
Density 70%		Density 90%		100% density	
Layer thickness [mm]	Time [min]	Layer thickness [mm]	Time [min]	Layer thickness [mm]	Time [min]
0.39	19	0.39	twenty	0.39	25
0.29	24	0.29	25	0.29	31
0.19	29	0.19	30	0.19	43

| 0.14 | 33 | 0.14 | 35 | 0.14 | 54 |
| 0.09 | 40 | 0.09 | 43 | 0.09 | 65 |

Source: Z-Suite Data (2022)

Table 1 generated values adjustable to the MN tool in order to obtain the function that defines the I3D process for the Zortrax M200 Plus (ZM200) equipment in the CE of the specimens in impact tests of ABS plastic material. It is observed that when obtaining the standard deviation as the Ec ~~decreases~~ ,decreases, the data are dispersed, which indicates the updating of the process to homologate the Te.

b) The choice of the MN was made based on the needs of the specific variables of the CE. The selected one was called *LaGrange interpolation* (IL), this provides the mathematical function and values for three subcases depending on the Ec (it is used in different printing equipment).

The values used in Ec for the IL are 0.3, 0.2 and 0.1, which are common in other MA models.

The objective IL is to find a polynomial function that passes through n+1 points and that has the lowest possible degree, considering equations (1), (2) and (3). This represents a linear combination that will result in a polynomial basis, dependent on the ordinates of P(x).

$$P(x) = \sum_{i=0}^{n} L_i(x) y_i \tag{1}$$

Basic LaGrange polynomial:

$$L_i(x) = \prod_{\substack{m=0 \\ m \neq 0}}^{n} \frac{x - x_m}{x_i - x_m} = \frac{x - x_0}{x_i - x_0} \cdots \frac{x - x_{i-1}}{x_i - x_{i-1}} \times \frac{x - x_{i+1}}{x_i - x_{i+1}} \cdots \frac{x - x_n}{x_i - x_n} \tag{2}$$

getting the property

$$L_{i(x_i) = \delta_{ij}} = \begin{cases} 1 & i = j \\ 0 & i \neq j \end{cases} \tag{3}$$

where y_i: ordered to the abscissa, x_i: abscissa and L_i: polynomial ~~notation~~notation.

c) For example: the programming of the evaluation case consisted of applying IL to the data in table 1. The first case was a) 10% in Ar, Ci and D; b) 0.39, 029, 0.19, 0.14 and 0.09 in ~~Ec ;~~Ec; c) 18, 23, 25, 27, 32 in Te and the polynomial function was as follows:

$$f(x) = \frac{(x-x_1)(x-x_2)(x-x_3)(x-x_4)}{(x_0-x_1)(x_0-x_2)(x_0-x_3)(x_0-x_4)} y_0 + \frac{(x-x_0)(x-x_2)(x-x_3)(x-x_4)}{(x_1-x_0)(x_1-x_2)(x_1-x_3)(x_1-x_4)} y_1 +$$

$$\frac{(x-x_0)(x-x_1)(x-x_3)(x-x_4)}{(x_2-x_0)(x_2-x_1)(x_2-x_3)(x_2-x_4)} y_2 + \frac{(x-x_0)(x-x_1)(x-x_2)(x-x_4)}{(x_3-x_0)(x_3-x_1)(x_3-x_2)(x_3-x_4)} y_3 + \frac{(x-x_0)(x-x_1)(x-x_2)(x-x_3)}{(x_4-x_0)(x_4-x_1)(x_4-x_2)(x_4-x_3)} y_4 \tag{4}$$

Substituting the values of the variables;

$$f(x) = \frac{(x-0.29)(x-0.19)(x-0.14)(x-0.09)}{(0.39-0.29)(0.39-0.19)(0.39-0.14)(0.39-0.09)}(18) +$$

$$\frac{(x-0.39)(x-0.19)(x-0.14)(x-0.09)}{(0.29-0.39)(0.29-0.19)(0.29-0.14)(0.29-0.09)}(23) + \frac{(x-0.39)(x-0.29)(x-0.14)(x-0.09)}{(0.19-0.39)(0.19-0.29)(0.19-0.14)(0.19-0.09)}(25) +$$

$$\frac{(x-0.39)(x-0.29)(x-0.19)(x-0.09)}{(0.14-0.39)(0.14-0.29)(0.14-0.19)(0.14-0.09)}(27) + \frac{(x-0.39)(x-0.29)(x-0.19)(x-0.14)}{(0.09-0.39)(0.09-0.29)(0.09-0.19)(0.09-0.14)}(32)$$

$$(5)$$

Factoring

$f(x) = (12000x^4 - 8520x^3 + 2137.2x^2 - 224.652x + 8.3311) + (-76666.6667x^4 + 62100x^3 - 16874.3333x^2 + 1866.91x - 71.5806) + (250000x^4 - 227500x^3 + 70525x^2 - 8645.25x + 356.265) + (-288000x^4 + 276480x^3 - 92332.8x^2 + 12469.248x - 566.9949) + (106666.6667x^4 - 107733.3333x^3 + 38837.3333x^2 - 5910.5067x + 320.9024)$ (6)

Therefore, the function is:

$f(x) = 4000x^4 - 5173.3333x^3 + 2292.4x^2 - 444.2507x + 56.927$ (7)

considering x=0.3, x=0.2 and x=0.1 f(0.3)=22.6838, f(0.2)=24.7821 and f(0.1)=30.6485

The data and function are reviewed with the purpose of generating the IL program in Python, which is demonstrated in the next stage.

Stage 3. Obtains the results of the model with the program, establishes its approval, generates the report of the parameters considered and provides feedback to the system.

Stage three are divided into four parts: 1) obtaining results, 2) approval of the MN and the results, 3) feedback of results to identify trends in the MN and 4) analysis report with the results obtained from the IL, which Are detailed below:

a) Obtaining results consists of programming the CE with Python. The purpose is to simplify the operations in the system and obtain the function of each of the test specimens. The CE program is described in Figure 4.

Figure 4 . Description of CE Programming with Python *Software*

```
# Interpolacion de Lagrange                    muestras = -----

    import numpy as np                          .....................

    import sympy as sym                         .....................

import matplotlib.pyplot as plt                 # Salida

                                                print('    valores de fi: ',fi)

# Ingreso . Datos de prueba                     print('divisores en L(i): ',divisorL)

xi = np.array([0.39, 0.29, 0.19, 0.14, 0.09])   .....................

fi = np.array([18, 23, 25, 27, 32])             .....................

                                                print(polisimple)

# Procedimiento

# Polinomio de Lagrange                         # Gráfica

    n = len(xi)                                 plt.plot(xi,fi,'o', label = 'Puntos')

    x = sym.Symbol('x')                         plt.plot(pxi,pfi, label = 'Polinomio')

    for i in range(0,n,1):                      .....................

        .....................                   .....................

        .....................                   .....................

        .....................                   plt.show()
```

Source: self made

Figure 4 shows the order and reference of data entry. There may be variations depending on the type of *software* used; Another way to do it is with C++. As for the programmer, experience influences, since he or she may delete actions described in the program or add extra stages to reinforce the solution.

a) The approval of the MN is observed when the results of the tests in the Python program are correct and comply with each of its steps.

b) The feedback of results is carried out as soon as the process is completed and mentions correcting: a) the results obtained from the CE, b) the analysis of the working group (interpretation, trends and future activities and possible applications for other types of products) and c) apply the identified improvements to the test specimen preparation process.

c) *dossier* ~~format .~~format, whose objective is to provide information on the process of the test specimens and describe the results obtained in a general way. The writing is public and easily accessible; For example, it can be located in the cloud to have greater interaction with those involved in numerical programming analysis topics.

Stage 4. Validation of the MN, facilitates the approved terms of the system and finalizes the numerical analysis process of the CE

Stage four is made up of three parts: a) validation of the theoretical model with programming, b) approved terms in the I3D and c) final process of the I3D and polynomial function by IL.

a) The validation of the theoretical model with the programmed one is carried out when obtaining the results of the calculations and the program. It consists of analyzing which of all the cases meets the processing conditions in the MA and how the application behaves on the different printing equipment. The characteristics of the specimen differ from the ZM200 equipment with which the tests were carried out. It should be noted that three phenomena of 0.3, 0.2 and 0.1 were studied, corresponding to the ~~Ec .~~Ec, which were the most common in commercial 3D printers.

b) The terms approved in the I3D predominate in the CE, with feasible and satisfactory results (table 2).

Table 2. Approved I3D MA parameters

No.	ZM200 parameters
1	~~You~~ Te [min]
2	D [10-90] [%]

| 3 | Ar [linear, hexagonal, three-dimensional and panel] |

Source: self made

Table 2 shows the parameters that predominate for use in the evaluation with the MNs and the functions obtained, which mark the analysis trend in future works of this nature with the use of the ZM200 equipment, where the numerical method applied was evaluated. to the case study.

c) The end of the process, for I3D and IL, is when the specimen is finished with the data obtained in the programming. In addition, compliance with the stages and substages of the methodology is reviewed again and it is identified if any element is required that offers benefits in the study with the variables and parameters located as part of the feedback that is required in any algorithm developed and applied in MA processes.

Results

This section offers the concentrate of the calculations made to the CE and the comparison of each of them together with the corresponding interpretation. Table 3 shows the functions for each of the cases analyzed in Table 1 with the corresponding graphs.

Table 3. Results of functions and evaluations in standard layer thicknesses

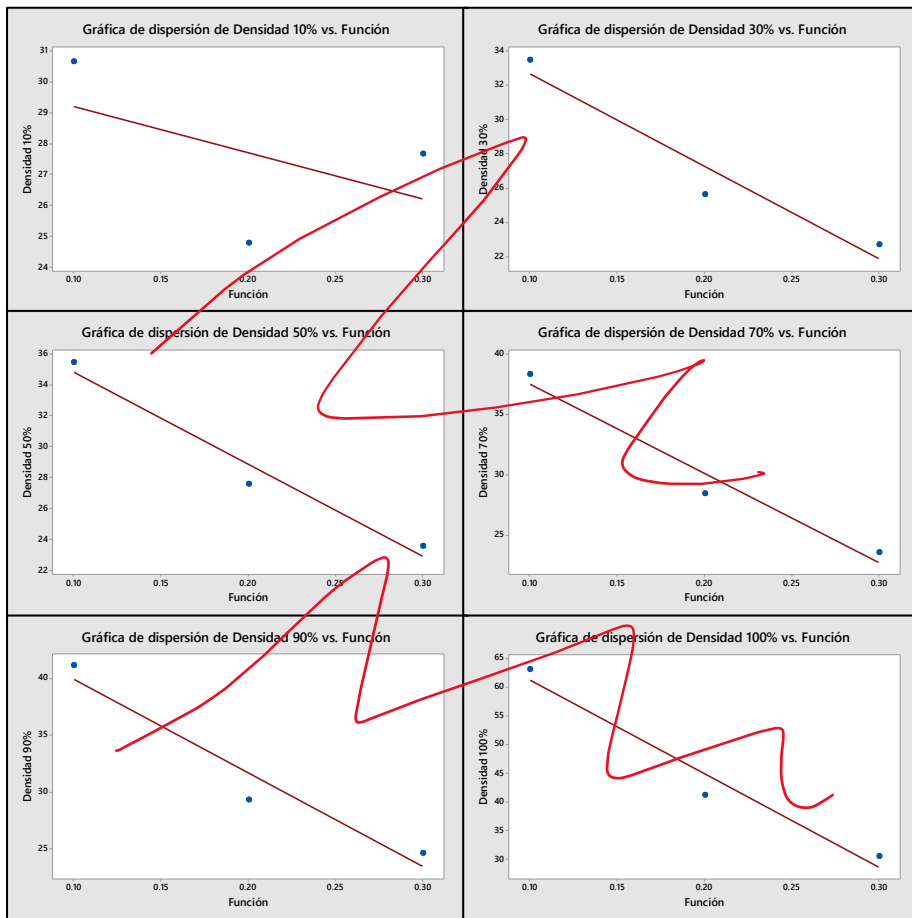| Density 10%		Density 30%	
$F(x)=4000x^4-5173.3333x^3+2292.4x^2-444.2507x+56.923$		$F(x)=3333.3333x^4-4366.6667x^3+2033.6667x^2-433.0033x+60.4622$	
F(0.3)	27.6838 [min]	F(0.3)	22.6912 [min]
F(0.2)	24.7821 [min]	F(0.2)	25.6082 [min]
F(0.1)	30.6485 [min]	F(0.1)	33.4652 [min]
Density 50%		Density 70%	
$F(x)=5333.3333x^4-6120x^3+2529.8667x^2-489.212x+64.6487$		$F(x)=4000x^4-4840x^3+2152.4x^2-4650484x+67.725$	
F(0.3)	23.5331 [min]	F(0.3)	23.5158 [min]
F(0.2)	27,743 [min]	F(0.2)	28.40 [min]
F(0.1)	35.4395 [min]	F(0.1)	38,026 [min]
Density 90%		100% density	
$F(x)=-1333.333x^3+1160x^2-373.0667x+68.152$		$F(x)=-16000x^4-1493.3333x^3-4249.6x^2+267.2027x+65.7118$	
F(0.3)	24.6319 [min]	F(0.3)	30.5286 [min]
F(0.2)	29.2719 [min]	F(0.2)	41.1150 [min]
F(0.1)	41.1119 [min]	F(0.1)	63.0294 [min]

Source: self made

Table 3 shows the data for the application of the MN of the IL: The values of the times for the deposition of the material are observed when making a prototype with advanced manufacturing,
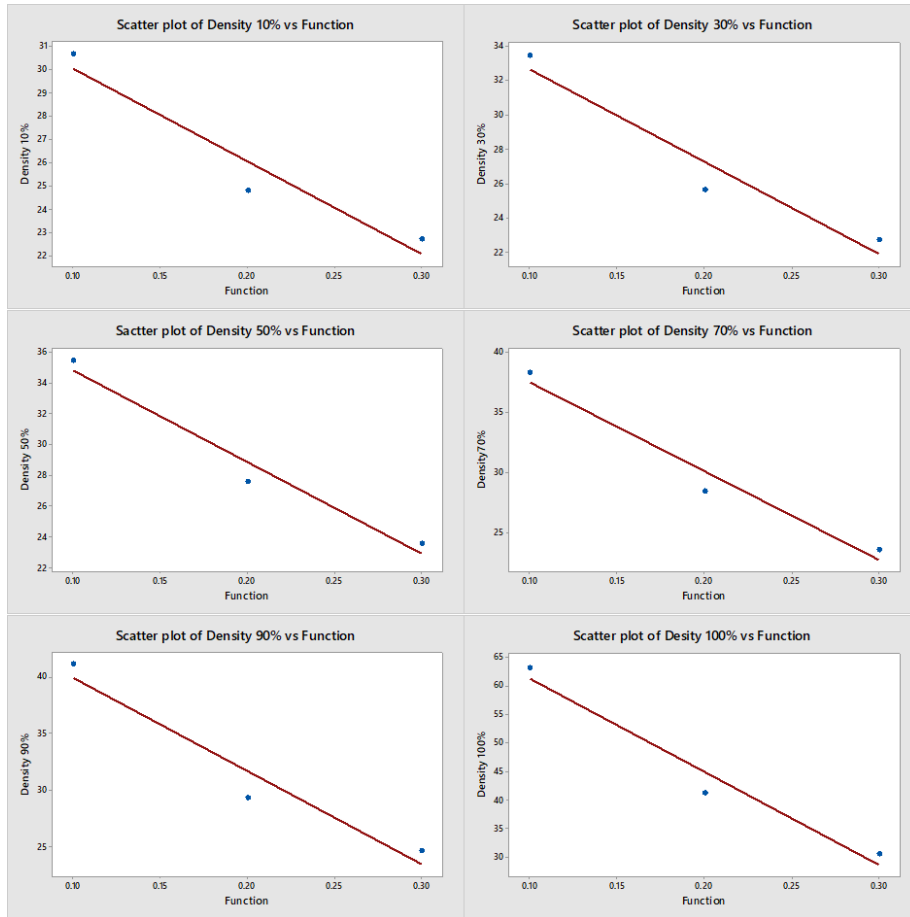
whose volume, specifically, must be 5.5 cm ^{3} . This volume is considered based on the CE for this work and is then extrapolated to other products made with I3D of regular geometry.

Figure 5 represents the data in graphs to determine the optimization of the model with respect to the percentage of D.

Figure 5 : Trend graphs to obtain the correlation coefficient (CC) in the CE

Source: self made

The data corresponding to the CC for each of the cases identified in Figure 5 are seen in Table 4.

Table 4 . Correlation coefficients for 10%-100% density

Density [%]	Correlation coefficient [CC]
10	0.2554
30	0.9345
~~fifty~~50	0.9668
70	0.9634
90	0.9402
100	0.9611

Source: self made

Figure 5 shows the trend graphs to obtain the CC in the CE, while table 4 shows that Ar with 50% D meets the MM objective because the CC is the one with the highest value (0.9668) and the model or function that performs the least, or on which work must be done to obtain an improvement, is the one that has 10% of the D.

From the same table 3 we see that the optimal times in processing the specimen are when f(0.3)=22.6912 with 30% in D, f(0.2)=24.7821 with 10% D and f(0.1)= 30.64 with 10 % D, while in the graphs of figure 5, according to the CC, the polynomial function that satisfactorily complies with the numerical analysis model is $F(x)= 5333.3333x^4 {}^{-6120x}3 {}^{+} 2529.8667x^2 -489.212x +64.6487$, with CC=0.9668 and D of 50%. These results must be contrasted experimentally, which can be modified in relation to the parameters considered in 3D printing with the ZM200.

Discussion

The work validated the importance of using MM with specific MN to MA with I3D for applied engineering. It should be noted that statistical aspects were evaluated that identified the generated functions or polynomials that offer the best result in terms of layer thickness, filling percentage and processing time.

Regarding the methodology and tools used, favorable results were obtained, because the D percentages that best fit for a specific product were identified, thereby generating trends for both the MA and the MN.

Likewise, it is important to note that the analysis of engineering processes is fundamental for the development of CE that involve time-dependent variables, which is why MN can be applied. On the other hand, basic elements of statistics are used to validate the functions obtained with the ~~MN~~ MN. According to Mesa *et al.* (2022), the use of numerical models in engineering applications is essential for research and data processing that favor the numerical environment in study cases

that can be modeled. In that sense, within his research the calculation of variance to verify the models stands out, where he found that this data is the same in the population that was considered in his structural engineering work.

In relation to LI, Tzu *et al.* (2022) consider that it is a control mechanism that guarantees security and confidentiality in each CE where it is applied. In this case, it was developed in the health sector with data from different hospitals. In this ~~way~~ ,way, IL was applied to achieve precision in medical diagnoses and tests to avoid repetitiveness in them.

On the other hand, a system was developed with LaGrange where users are identified with random codes, avoiding the media relationship of easy-to-identify codes. A dynamic control was established to ensure the security of the encrypted medical information system in a secure and stable manner, which, in turn, improves medical care by helping professionals make appropriate decisions with the result applied in this study. Taking this research into account, a comparison is achieved by formulating a model that ratifies the use of NMs, where polynomial functions are used to define, conceptualize and provide solutions to case studies in applied science.

Conclusions

From the general point of view, the work has a particular analysis methodology because it is a CE whose tendency is to be applied in different products made with MA and show the usefulness of this as a standard format for numerical analysis.~~.~~

In relation to the CE, the test specimen is considered in the impact tests for specimens of plastic material because it has been observed that, in this test, the MM are only a function of energy, and the process is not taken into account. of manufacturing, hence the interest in generating new variants in the modeling of the I3D process to have a support tool when establishing optimization of specimens with certain specifications.

During the development of the work, variants derived from experimentation are identified, which at the time have been considered as control parameters in the I3D process, which have areas of opportunity to continue carrying out analysis; For example, controlling the Ci and Ar with which a product is manufactured, given that they are elements that entail physical effects such as resistance, durability and energy absorption.

Likewise, it should be remembered that the model obtained was only for one specimen and that the results shown in Table 3 have an approximate error percentage between 14% and 25%, which corresponds to the material deposition time to generate a product.

In this study there are two contrasts: on the one hand, the function obtained through IL offers optimal results for the case in which there is 10% in the D for the manufacture of the specimen, and, on the other, in the graphics, the optimal function is for when there is 50% D, so it is necessary to use some other MN to corroborate which process should be applied to the manufacture of products in I3D. This, therefore, represents an area of opportunity for MA with numerical analyses.

One of the particularities in this development was to keep two parameters constant: Ar and Ci, which were taken into account in this way to control the mathematical process; However, in the future, modeling will be carried out with more Ar to allow greater variability in the modeling and analyze the optimization of the AM with that specific element.

With this work we have the advantage and main idea of applying MM to innovative industry processes that enrich knowledge to extrapolate the optimization of MA in the various application sectors. In this way, it is expected to increase the interest in further studying the characteristics, parameters and criteria in 3D printers as an essential part of the trends offered by technologies within engineering.

Future lines of research

In the next case studies for the MA based on the MN, specific control variables are established, among which the range of materials to be used in the 3D, the fusion temperature of the materials, the volume of the case study are considered. , the different types of ~~arrangement~~ pattern used in the preparation of the specimen depending on the printing equipment used, the percentage of infill linked to the types of ~~arrangement~~ pattern that will delimit the physical properties of the materials used, the support material, the detachment angle and the quality of the specimen.

When using AM with I3D, it is considered appropriate to analyze more than five pieces of equipment of this type with the purpose of standardizing the specimen preparation processes as part of the analysis in the case studies and generating processes with a maximum of 10%. of error in each processing after applying MN. This implies implementing a maximum of three MN that contemplate the same variables and conditions for the evaluation as was carried out with IL.

Likewise, it will be convenient to use methods such as the design of experiments with *n* factors to increase the analysis of variables and compare with experimental data obtained from other more common 3D printing equipment on the market, both national and international. In this way, the feasibility of using MA in each case study can be determined, whose areas of interest to review will be linked to the industry. In addition, promote research-industry synergy to strengthen both sectors and impact new technology trends and process optimization.

Finally, generate collaborative groups whose profiles are aimed at the design of experiments, statistical analysis, process evaluation, optimization and computational simulation for the development of new case studies in MA with I3D.

Conflicts of interest

The authors declare that there is no conflict of interest.

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