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Presentation of the Content

In the first article we present, *Analysis and Control of a three-phase motor using a neural network*, by Hernández-Epigmenio, Miguel Ángel, Martínez-Carrillo, Irma, Juárez-Toledo, Carlos and Camacho- Altamirano, Ulices, with adscription in the Universidad Autónoma del Estado de México; as next article we present, *Experimental investigation of FFF process parameters using carbon fiber reinforced PETG material by Taguchi analysis*, by Martínez-Cervantes, J. Alan, Sánchez, Luis Javier and Aguilar-Duque, Julian I., with adscription in the Universidad Autónoma de Baja California; as next article we present, *Thermal-structural numerical analysis of the brake and disc system of a Formula SAE 2024 type vehicle*, by López-Flores, Jennifer-Guadalupe, Cordero-Guridi, José de Jesús, Ovando-Cuevas, Enrique Romeo and Yescas-Ávila, Eber Alonso, with adscription in the Universidad Popular Autónoma del Estado de Puebla; as next article we present, *Evaluation of operational efficiency in a company dedicated to the manufacture and sale of coolers*, by Cano-Carrasco, Adolfo, González-Mendivil, Manuel Antonio, Fornés-Rivera, René Daniel and Noriega-Olivas, Israel, with adscription in the Instituto Tecnológico de Sonora; as next article we present, *Design of a photovoltaic performance prediction model using meteorological models and machine learning techniques*, by González-Ramírez, Claudia Teresa, Ruiz-Garduño, Jhacer Kharen, Martínez-Alcantar, José Luis and Viñas-Álvarez, Samuel Efrén, with adscription in the Instituto Tecnológico Nacional de México; as final article we present, *Statistical analysis of the proportion of recycled edible oil in the quality of scented candles*, by Ramos-González, Luz María, Cruz-Orduña, María Inés, Vicente-Pérez, Brisia Joseline and Velázquez-Martínez, Victor, with adscription in the Universidad Veracruzana.

Content

Journal-Mathematical and Quantitative Methods 8[14]1-09: e10814109
Article

Analysis and Control of a three-phase motor using a neural network

Control y análisis de un motor Trifásico usando una red neuronal

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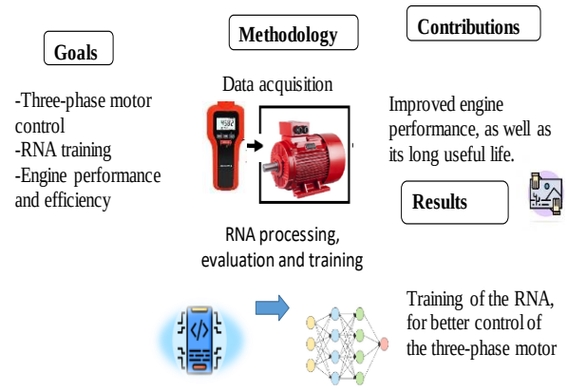
Abstract

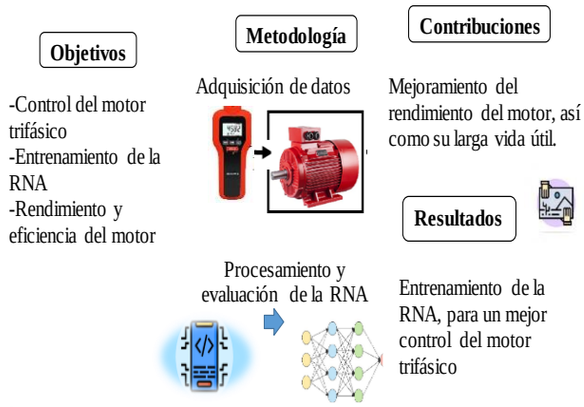
Actually the electrical power systems analyzed in automatic control we find the systems: dynamic, linear, triphasic induction motors, their operation can be validated, through their mathematical model, and thus represent their parameters for a real physical motor. This has a high degree of feasibility of being controlled because a more precise approximation of its dynamics can be known. Guarantee optimal energy consumption and performance of a three-phase motor, large companies have bet on artificial intelligence and the quality of proper operation in their new electric motors. This work has the purpose of carrying out an analysis on the operation of a three-phase electric motor for commercial use, is of vital im-portance to know the parameters of the real three-phase motor so that they allow an efficient use of energy and in addition to designing efficient and robust control schemes. Additionally the analyzed operation and manipulation and the training of a neural network (RNA) utilize MATLAB. Main contribution of this document is to experimentally validate the training of the RNA, taking real parameters on the manipulation of a triphasic motor. Training, the results can be used to improve engine performance as well as engine life.



Analysis, manipulation, neural, validate, consumption

Resumen

Actualmente en los sistemas eléctricos de potencia analizados en control automático encontramos los sistemas: dinámicos, lineales, etc. Los motores de inducción trifásica se les pueden validar su funcionamiento a través de su modelo matemático y computacionalmente, para así representar sus parámetros en un motor físico real, ante ello se tiene un alto grado de factibilidad de ser controlado debido a que se puede conocer una aproximación más precisa de su dinámica. Para garantizar un óptimo consumo de energía y rendimiento de un motor trifásico, las grandes empresas le han apostado a la inteligencia artificial y a la calidad de un buen funcionamiento en sus nuevos motores eléctricos. Este trabajo tiene la finalidad de realizar un análisis, control y funcionamiento de un motor eléctrico trifásico de uso comercial. Para ello es de vital importancia de conocer los parámetros de un motor trifásico real que permitan realizar un uso eficiente de la energía y además diseñar esquemas de control eficientes y robustos. Además se analiza el funcionamiento y manipulación por medio del entrenamiento de una red neuronal (RNA) .La principal contribución de este documento es validar experimentalmente el entrenamiento de la RNA, tomando parámetros reales sobre la manipulación del motor trifásico. Estos resultados de entrenamiento se pueden utilizar para el mejoramiento del rendimiento del motor, así como su vida útil.



Análisis, manipulación, neuronal, validar, consumo

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Graphical overview

Origins of electrical machines go back to the 19th century, when Oersted, Faraday, Henry, Lenz, Barlow, and Maxwell began to apply and develop basic principles of electromagnetism. Specifically, the principle of electromagnetic induction, discovered by Faraday in 1831, can be considered as the origin of studies on electrical machines (Ben-Brahim et al., 1991).

In 1890 Dolivo Dobrowolsky invented the three-phase asynchronous motor, using a squirrel-cage rotor and using a distributor winding in the stator.Electric motors transform electrical energy into mechanical. The action of these is carried out by introducing a cur-rent into the machine through an external power supply, this current interacts with an inductor magnetic field, producing a torque that causes the movement of the machine (Pedra et al., 2005).

Three-phase machine the industrial motor of excellence, due its characteristics of reliability, robustness and high power/weight constitutes the vast majority of in-stalled power in drives industrial, this motor consist of a fixed part or stator, and a part-mobile or rotor, separated by a small air space called the air gap, these three parts, stator, rotor and air gap are part of the magnetic circuit machine (Chapman et al., 2020).

Asynchronous or induction machine, any other electromechanical energy conversion device of the rotary type, is made of a stator and a rotor. Inductor is normally placed in the stator, fed by a three-phase network, the rotor is the armature, and the currents that flow through it appear as a consequence of the interaction with the stator flow (Dugan et al., 1996).

Depending on the type of rotor, these motors classify in:

- Rotor in squirrel cage or in short circuit.
- Rotor wound with rings.

(Montanari et al., 2006) induction motors (or asynchronous motors), three-phase motors are the most used in the Industry they operate at essentially constant speed from zero to full load. (Pedra et al., 2005) speed depends on the frequency, so these motors do not adapt with ease to speed control, however, electronic controllers are increasingly being used variable frequency to control the speed of commercial induction motors.

Development and emergence of new technologies focused on the automotive sector and manufacturing in general in the subject of industrial engines that, through its autonomy in the execution of tasks, has become more sophisticated every day for the increase in the productivity of a Company (Demir et al., 2016).

Today industries where presence of three-phase motors to make changes from electrical energy to mechanical energy, have always been more efficient, smaller and lighter than those of 120 years ago, Basic principle has not changed much with its respective maintenance and repair schemes throughout its useful life, due to its continuous and demanding use, this particular group of electric motors are subject to adverse operating conditions that can cause wear, overloads and other problems that affect your performance and life (Sato et al., 2011).

(Hiramoto et al., 2014) electric induction motors are part industrial essential process; his robustness, low cost, easy maintenance and versatility have made them popular applications rang-ing from artifacts home appliances more sophisticated equipment industrial or auto-motive type. (Dawood et al., 2024) the engines have their limitations and they are exceeded will result in premature stator failure or rotor.

Artificial intelligence in the fields of power electronics and electric drives have in-creased considerably. Modern techniques are mainly based expert systems, fuzzy logic and neural networks used for control and facilitate decision making from a logical analysis based on prior knowledge or data that describe operation of the system (Villada et al., 2007).

(Nazemi et al., 2024), neural network presented architecture detect short circuits in the stator winding. Failure indicator is the percentage of turns failed; network structure was multilayer perceptron with nine neurons in the hidden layer.

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(Di Stefano et al., 1994) developed a network to diagnose faults between whorls. The training data was obtained using a model based on the space vector theory. The indicator failure used was the percentage of turns failed. After training and validating the network, the error was less than 2.4%. Although the method is good, the drawback lies in the characteristics of the model for being very complex to implement.

(Tallam et al., 2001) RNA proposed using sequence components voltage and current for fault detection between turns in an induction motor. RNA estimated current sequence negative, which used as an indicator of failure.

Article presents the analysis of and operation of a three-phase motor with known Characteristics, as a second instance according to its operating parameters of the induction motor, the training and automatic learning of a neural network is proposed to be able to manipulate the motor and obtain better performance, efficiency, energy savings and extend its useful life.

Methodology

Next section describes the acquisition of voltage and speed test data from the three-phase motor, three phase motor specifications, and the neural network test system developed for its validation. Figure 1 shows the steps of the proposed process, followed by the results section.

Box 1

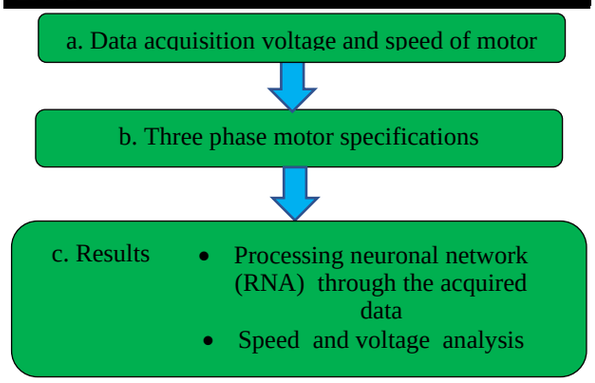

Figure 1

Flowchart of the study

Source: Own elaboration

a. Data acquisition voltage and speed of motor

Section describes the measurement of numerical data the motor speed and its respective voltage was practically carried out.

For the connection of the three-phase motor is carried out and its operation parameters are adjusted by means of a frequency inverter once, this is done, a tachometer is connected to measure the speed of the motor with respect to its input voltage, in summary speed is manipulated with respect to its voltage, figure 2.

Variation of voltage (0-10 volts) manipulated potentiometer and in turn by a servomotor, which is automatically manipulated by the neural network in Matlab, the voltage is read by a multimeter. The total was made up of 100 voltage readings and 100 speed readings (RPM).

Box 2

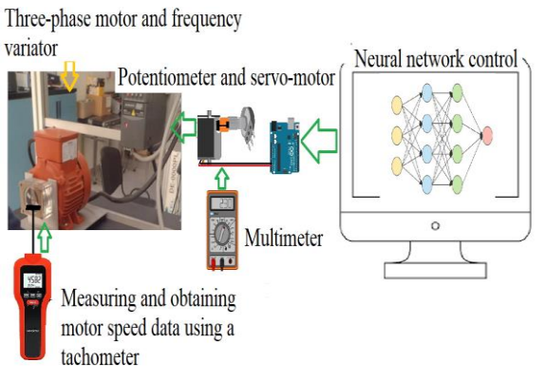

Figure 2

Physical connection of the motor and data acquisition

Source: Own elaboration

b. Three phase motor specifications

(Wildi,2007) three-phase motor generally the stator winding is made up of three windings 120° out of phase in the space of 2 poles. By introducing currents from a triphasic network of frequency Fi through them, a rotating wave is produced sinusoidally distributed around the periphery of the stator air gap that produces a rotating flux whose speed is expressed by:

$$\Omega_1 = \frac{2 \cdot \pi \cdot f_1}{p} \left[\frac{\text{rad}}{\text{s}}\right]$$

$$\text{n}_1 = \frac{60 \cdot f_1}{p} [\text{rpm}] \qquad [1]$$

Where:

Ω_1 and n_1 = are synchronization speed
p = number of pairs of poles
f_1 = frequency

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Operating principle

(Wildi,2007) induction motors with cage type rotor squirrel, with wound rotor and linear with large horsepower capacities have allowed the reader to see that they operate on the same basic principles as a normal motor. Three-phase induction motor consists two main parts: a stationary stator and rotating rotor. The rotor is separated from the stator by a small air gap ranging from 0.4 mm to 4 mm, depending on the power of the motor.

- Stator: consists a steel frame supporting a composite hollow cylindrical core of stacked laminations. Several slots equidistant from each other, made in the inner circumference of laminations, provide space stator winding.
- Rotor: composed of slotted laminations. are stacked neatly to create a series of slots for the rotor winding.

Two types rotor windings are used: (a) conventional three-phase windings made of wire insulated and (b) squirrel cage windings.

The kind winding gives rise to two main classes of motors:

- Squirrel cage induction motors (also called cage motors).
- Induction motors wound rotor.

(Wildi, 2007) and (Glowacz et al., 2024) operation motor consists introducing a three-phase frequency current where a rotating magnetic field produced whose speed is expressed by measuring voltage. Figure 3 shows the representation of a three-phase current motor and its electrical diagram.

Box 3

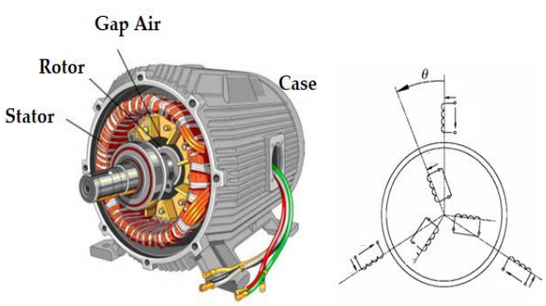

Figure 3
Representation three-phase motor and electrical diagram
Source: (Wildi,2007)

(Wildi, 2007) equivalent circuit of a three-phase induction, the motor has 3 identical primary windings and 3 identical secondary windings (one game for each phase). Its perfect symmetry, we can consider a single primary winding and a single secondary winding when analyzing motor behavior. When the motor is at rest, it acts exactly like a conventional transformer, so its equivalent circuit the figure 4 is shown.

Box 4

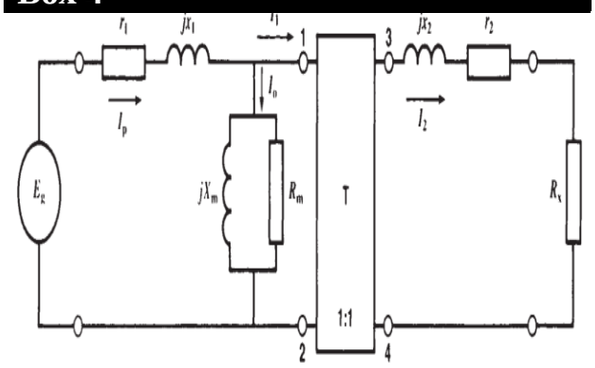

Figure 4
Equivalent circuit of the induction motor
Source: (Wildi,2007)

For the connection motor in (Y) for the stator and the rotor and a turns ratio of 1:1. The parameters of the circuit, by phase, are identified as follows:

E_E = source voltage, line to neutral
r_1 = stator winding resistance
X_1 = stator leakage reactance
X_2 = rotor leakage reactance
r_2 = rotor winding resistance
R_x = external resistance, effectively connected between a slip ring and the neutral of the rotor
X_m= magnetizing reactance
R_m= resistance whose losses correspond to theiron losses and friction losses rolling and air friction (mechanical losses)
T = ideal transformer with a ratio of 1:1 turns

Three-phase motor used in this work connected star, the following figure 5, shows the internal and external part of the rotor.

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Box 5

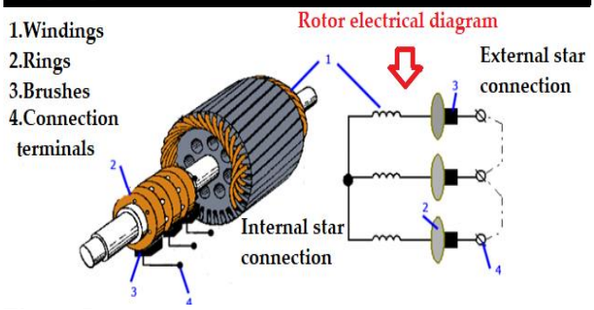

Figure 5

Internal and external components and star connection of a three-phase rotor

Source: (Wildi,2007)

Characteristics and factory specification parameters of the motor used in this work are shown in the following table 1.

Box 6

Table 1

Triphasic motor specifications Source

Frecuency	60 Hz
Voltage	220 v
Current	1.6 A
Nominal power	0.25 Kw
Nominal speed	4000 (RPM)

Source: Own elaboration

Results

Processing neuronal network (RNA) through the acquired data

(Incio et al., 2023) artificial neural network is computational mathematical model that attempts to emulate behavior neurons in human brain developed learning through experiences, composed processing units interconnected with each other, capable of recognizing patterns, classifying data and forecasting future events with precision and accuracy. In the figure 6 see the architecture neural network with an input layer, two hidden layers and an output layer.

Box 7

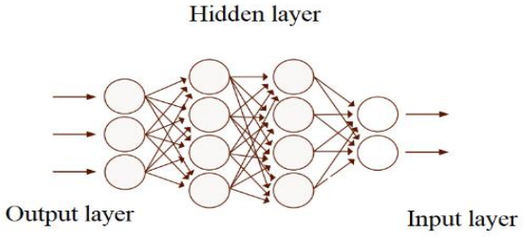

Figure 6

Typical architecture of a neural network

Source: (Incio et al.,2023)

(Lobo et al., 2018) artificial neural network (RNA) a system composed of many simple processing elements operating in parallel whose function determined by the structure of the network, connections, and by the processing performance computational elements or nodes, shows figure 7.

Box 8

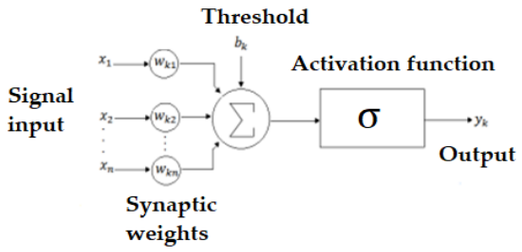

Figure 7

Block diagram of a neural network (RNA)

Source: (Incio et al.,2023)

(Haykin,1999), neuron basic unit information processing of a neural network, where the output can be written as expressed in equation 2.

$$y_k = \sigma\left(\sum_{j=1}^{n} \omega_{jk} \cdot x_{j+} b_k\right) \quad [2]$$

Where:

y_k= output information from the neuron

x_j, x_n= input signal.

$\omega_{k1}, \omega_{k2}, \omega_{kn}$= are the synaptic weights corresponding to the neuron *k*

b_k= is the threshold

σ = activation function

Figure 8 shows the block diagram of the neural network proposed for the control of the three-phase motor.

Box 9

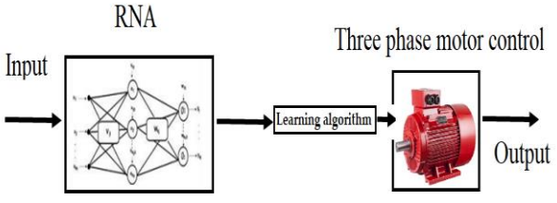

Figure 8

Blocks diagram (RNA) for control triphasic motor

Source: Own elaboration

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Next table 2 shows concentration of numerical data in real time of the three-phase motor when it is running, this data (speed and voltage), allow the correct learning of the neural network.

Box 10

Table 2

Training input data (RNA)

Speed($\frac{rad}{s}$)	Voltage
36.86	1
40.63	1.1
43.24	1.2
48.27	1.3
50.16	1.4
56.12	1.5
61.26	1.6
67.64	1.7
68.48	1.8
69.21	1.9
75.92	2

Source: Own elaboration

Data in table 2 are input data to training the RNA in MATLAB. Figure 10 shows the performance of the neural network with 2 layers and 10 neurons. The figure 10 shows four 4 aspects resulting from the RNA which are: training, validation, test, best.

Box 11

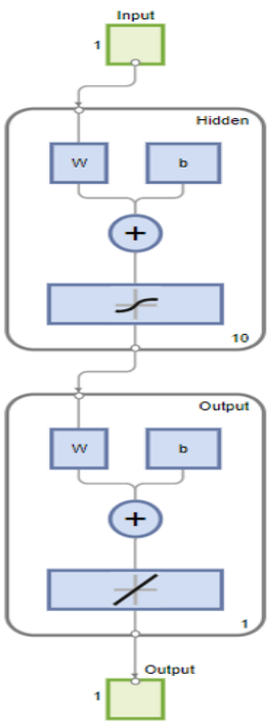

Figure 9

Feed-forward neural network diagram with 2 layers and 10 neurons

Source: Own elaboration

Figure 9 shows neural network diagram pre-fed with 10 neurons, it also shows only training output.

Four elements of the performance of the neural network mentioned above can be seen in the figure 10. When learning algorithm begins to generalize the input data, the training (blue) and validation (green) generalize to the best training, resulting in the period (305) marked by the circle is the best period. the test in (red) is optimal for training.

Box 12

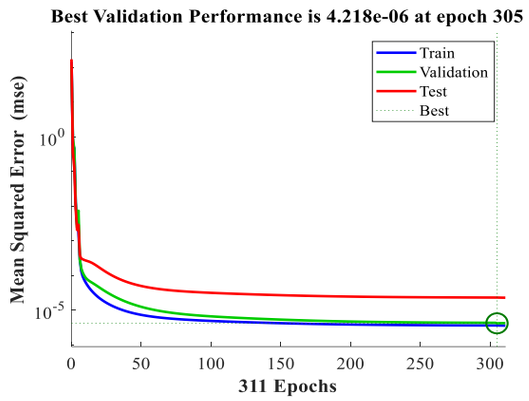

Figure 10

Performance and training neural network (RNA)

Source: Own elaboration

Neural network its learning algorithm learns to manipulate three-phase motor shown in the figure 2, where the potentiometer moves from (0-10 volts) in automated manner and controlled by proposed RNA.

Figure 11 shows linear regression of the network outputs (validation, training, testing and the best one that corresponds to figure 10).

Perfect fit, data shown along a 45 degree line, show that the outputs of the network are equal to the objectives (Y=T) with minimum alignment gaps.

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Box 13

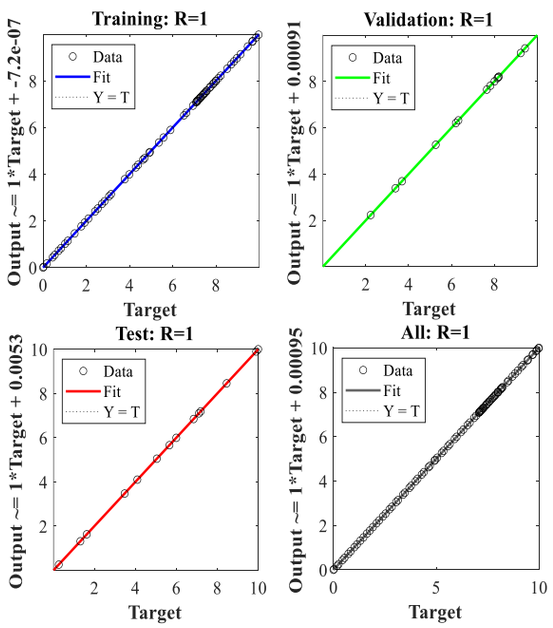

Figure 11
Regression neural network (RNA)
Source: Own elaboration

- *Speed and voltage analysis*

(Cubides et al., 2017) and (Auger et al., 1995), an important indicator processing spectral density signals is the speed-voltage relationship is the (periodogram),which power spectral density (PSD o $\hat{P}$(f). Specifies the estimation of the power spectrum from periodogram of a sinusoidal of two channels relating spectral powers, where mathematically represented as:

$$\widehat{P}(f)=\frac{\Delta t}{N}\left|\sum_{n=0}^{N-1} x_n e^{-j2\pi f\,\Delta t\, n}\right|^2$$
$$,\frac{1}{2\Delta t} < f \leq 1/2\Delta t \qquad [3]$$

Where power spectral signal, in samples per unit time, the periodogram is definedfs. For Δt is sampling interval. For one-sided crossover, the values at all frequencies except 0 and Nyquist, $1/2\,\Delta t$, are multiplied by 2 the full power of the signals preserved. Figure 12 shows the power spectral signal of the engine speed marked in brown and the voltage spectral signal in blue.

Box 14

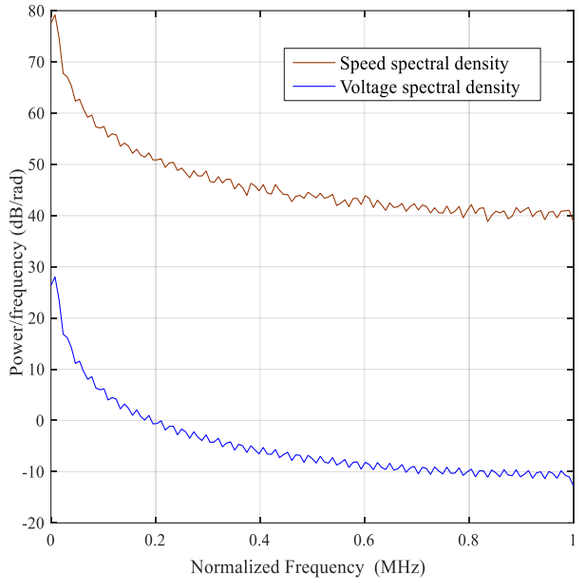

Figure 12
Spectral density of motor speed and voltage
Source: Own elaboration

Conclusions

In conclusion the article proposes control and analysis of a three-phase motor through a two-layer neural network and 10 neurons depending speed and voltage. Results showed effectiveness of this proposed method to be able to manipulate the motor automated manner, increase its efficiency, useful life and minimize its energy consumption in the short and medium term, while the motor is running. Neural network and its automatic learning and effective tool for engineering investigation and technology.

In addition to this today electric motor industry it is required to know the effectiveness of a motor on the market and performance in order to improve and control them.

Figure 10, 11 show basic procedure for the functioning of RNA, where optimal number of neurons is chosen to generate training and learning optimally and quickly. Network examines the 100 input data and at period 305 of the figure 10 shows a good workout.

In addition to this for a company that has adapted three-phase motors in its manufacturing processes, the method current can be applied to guarantee the useful life of your equipment and choose an optimal and appropriate way their management, monitoring and maintenance.

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Future works surrounding this, the control could be implemented and adapted the engine through a genetic algorithm or perceptron.

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Authors' Contribution

The contribution of each researcher in each of the points developed in this research is the following:

Hernández-Epigmenio, Miguel Angel: Contributed the idea the project the development of the proposed research method and technique. He carried out data analysis and systematization of results, in addition to writing the article.

Carrillo-Martinez, Irma: She carried out the systematization and background advice for the state of the art and development of the proposed method. She supported the design of results. She also contributed to the writing of the article.

Juárez-Toledo, Carlos: contributed to the research design, approach, development of the proposed method and analysis of results as well as writing the article.

Camacho-Altamirano, Ulices: worked on the application of the field instrument, data collection and systematization of the results. He also worked on the writing of the paper.

Availability of data and materials

Data obtained from the measurements carried out were analyzed in the laboratory of the Autonomous University of the State of Mexico.

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Abbreviations

RNA	Artificial Neural Network
RPM	Revolutions for minute

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Article

Experimental investigation of FFF process parameters using carbon fiber reinforced PETG material by Taguchi analysis

Investigación experimental de los parámetros del proceso FFF aplicando el material PETG reforzado con fibra de carbono mediante el análisis Taguchi

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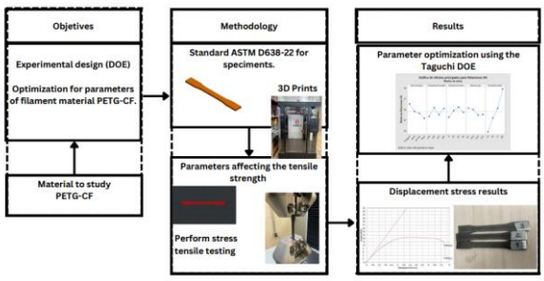
Abstract

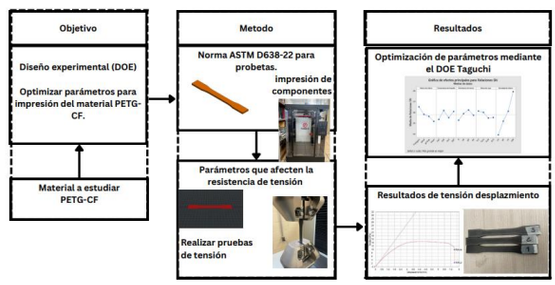
Fused filament fabrication (FFF) is a popular additive manufacturing technique with the ability to produce products in industries such as automotive, aerospace, and medical due to the potential for material waste and the manufacturing of complex geometries with different materials. For high-strength parts, it is crucial to investigate and optimize printing parameters to make the printed parts as strong as possible. This work will focus on the experimental investigation of parameter optimization for the strength of carbon fiber reinforced PET-G (PETG+CF), which is carried out using Taguchi's method and the samples were produced according to the orthogonal matrix L16 and to study if influence by ANOVA (analysis of variance). It was possible to conclude that the best parameters for the tensile strength of PETG+CF with temperature of 250° C, part orientation at 60°, layer height of 0.30mm, 100% fill density and with triangle fill pattern.



Fused filament fabrication, PETG-CF, Taguchi; ANOVA Analysis of variance

Resumen

Actualmente en los sistemas eléctricos de potencia analizados en control automático encontramos los sistemas: La fabricación por filamento fundido (FFF) es una técnica popular de la fabricación aditiva con capacidad de producir productos en industrias como la automotriz, aeroespacial y medica debido al potencial de desperdiciar material y la fabricación de geometrías complejas con distintos materiales. Las piezas de alta resistencia es crucial investigar y optimizar los parámetros de impresión para que las piezas impresas sean lo más resistentes posibles. Este trabajo se centrará en la investigación experimental de la optimización de parámetros para la resistencia del PET-G reforzado con fibra de carbono (PETG+CF), se lleva a cabo utilizando el método de Taguchi y las muestras se produjeron de acuerdo con la matriz ortogonal L16 y para estudiar si influencia mediante ANOVA (análisis de varianza). Fue posible concluir que los mejores parámetros para la resistencia a la tensión del PETG+CF con temperatura de 250° C, orientación de construcción a 60°, altura de capa de 0,30mm, densidad de relleno al 100% y con patrón de relleno a triangulo.



Fabricación por Filamento Fundido, PETG-CF, Taguchi; ANOVA Análisis de varianza

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Introduction

Additive Manufacturing

In accordance with (ISO/ASTM52900, 2015), Additive Manufacturing (AM) is a process of joining materials to fabricate parts from three-dimensional model data, usually layer by layer as opposed to subtractive and, formative manufacturing methodologies.

Currently, AM is a manufacturing strategy that is evolving daily, since it is changing paradigms of subtractive manufacturing. The objective of this type of AM is to save time, reduce material costs, and have complex designs that give freedom of design to engineers and designers. (Bravo Marmolejo & Diosdado De la Peña, 2017).

In recent decades the rise and rapid maturity of additive manufacturing process technology has brought many benefits to engineering by opening up many manufacturing methods or processes. The current methods to date are stereolithography (SLA), laser engineered network forming (LENS), fused filament manufacturing (FFF) or fused deposition modeling (FDM), inkjet modeling (IJM), digital light processing (DLP), laminated object manufacturing (LOM), selective laser sintering (SLS), and electron beam melting (EBM) (Bikas, Stavropoulos, & Chryssolouris, 2016). Their applicability can be found in different fields such as automotive industry, agriculture, medicine, etc. (Dal Maso & Cosmi, 2019; Zuniga et al., 2015).

MA growth has been 16% for industrial production and for professional services, 40% for personal use, and the desktop and custom markets. (Ontiveros, Báez, Aguilar-Duque, & Limon, 2023). It is important to note that the reason for the increase is that the effective use of additive manufacturing is related to the reduction of material waste generated by the process, while in additive manufacturing requires a material that its use is from post-processing by building material deposition layer by layer.

The intensive search they conducted, (Ontiveros et al., 2023) different companies are using additive manufacturing technology, the most important information about the level of adoption is shown in Figure 1.

Where 18% of the automotive industry makes use of additive manufacturing compared to 52% of the medical industry.

Box 1

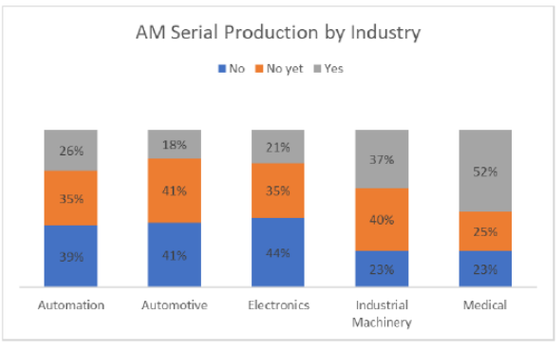

Figure 1

Percentage of additive manufacturing adaptation in production

Source: (Ontiveros et al., 2023)

Fused filament fabrication FFF

In this research, FFF will be used to make the printed models, it works by melting a thermoplastic and extruding it layer by layer through a nozzle to create the model according to the geometric data of the 3D CAD (computer aided design) model (Kun, 2016) as shown in Figure 2.

Box 2

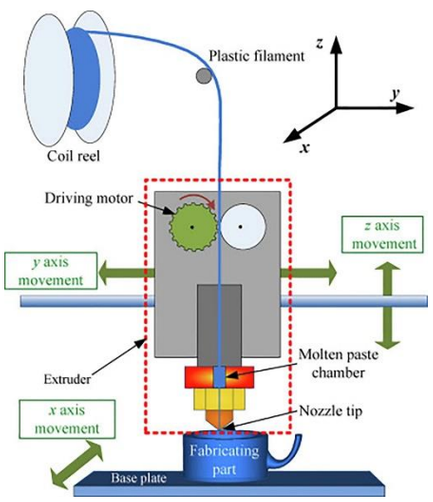

Figure 2

Schematic representation of the working principle of the FFF process

Source: (*Jin, Li, He, & Fu, 2015)*

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One of the critical aspects of FFF is the dimensional accuracy of the printed models, especially in engineering applications (Buj-Corral & Zayas-Figueras, 2023). The dimensional accuracy of a printed model in general is to ensure proper fit and assembly to maintain quality prototypes or functional products, especially in the engineering area as FFF is used for prototyping for certain areas such as aerospace or automotive (Najmon, Raeisi, & Tovar, 2019). They are also used in toys such as moving dolls or remote-controlled cars and in electronic component units (CD players, electronic toothbrushes) (Gibson et al., 2015; Gupta, 2018; Maurya, Rastogi, & Singh, 2021). It has also been applied to the field of architecture for the recreation of models and projects related to the field. (Wohlers, Campbell, Huff, Diegel, & Kowen, 2019).

FFF printing has a subset of materials that are compatible for modeling, for example, there are different materials available in the market such as; Polylactic Acid (PLA), Acrylonitrile butadiene styrene (ABS), Polycarbonate (PC), and different types of Nylon (PA). (Wong & Hernandez, 2012). However, the development of new carbon fiber reinforced filaments with improved mechanical properties such as the PA6 patented by 3DXTech (Jesús Miguel Chacón, Caminero, Núñez, García-Plaza, & Bécar, 2021). The study by (Zhang, Purssell, Mao, & Leigh, 2020) evaluated the fabrication of nylon polymer gears, specifically spur gears which were printed with FFF on Ultimaker S2 and Markforged X7 printers using nylon 618, nylon 645 and nylon 910 filaments, along with Onyx and Markforged proprietary materials and performed on a custom gear wear test bench and as a result showed that nylon 618 provided better wear performance.

Analysis of control parameters for FFF manufacturing

In the MA using the FFF process involves setting certain values for the various variables found in the process. These can all be entered with the help of software or the machine control unit and construct so-called input parameters.

Figure 3 shows an extended cause and effect diagram of the FFF technology for obtaining correct dimensional accuracy (PD) and surface quality (CS) (Mosleh, Rezadoust, & Dariushi, 2021; Tsiolikas, Mikrou, Vakouftsi, Aslani, & Kechagias, 2019; Väisänen, Hyttinen, Ylönen, & Alonen, 2019).

Box 3

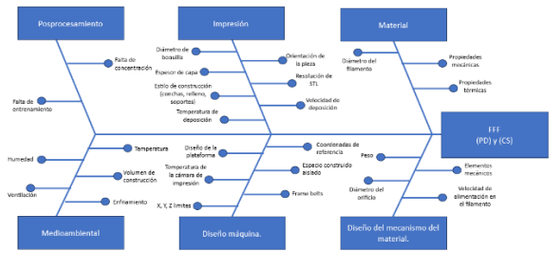

Figure 3

Cause and effect diagram of the FFF process control parameters

Several parameters have a significant impact on the shape of the parts produced and how they are manufactured. Some of the most important parameters include layer thickness, printing speed, build orientation, fill density, fill pattern, extrusion temperature, nozzle diameter, etc. (Dey & Yodo, 2019). All the methods to add strength to mechanical properties in 3D printed models are very useful, but the most important part has to do with the optimization of printing parameters. Basically, this optimization helps to improve the performance of the system using the above methods.

Therefore, it is not surprising that the literature indicates that FFF is the first and most important step in improving the mechanical properties of printed parts. Of all the printing parameters, the literature recommends that the most influential parameters are layer thickness, air gaps, filler density, temperature, and printing speed (Mohamed, Masood, & Bhowmik, 2015). However, due to the complex interaction between the parameters, they should be analyzed together as a group (Ngo, Kashani, Imbalzano, Nguyen, & Hui, 2018). For this purpose, several design of experiments (DOE) procedures are found in the literature; one of the most commonly used procedures is Taguchi. (Singh, Birru, & Singh, 2024) for example optimized the parameters to reach dimensional accuracy with PLA material with application to femur bones using a Taguchi L16 technique.

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According to the authors while printing speed and layer height were the determinants for dimensional accuracy. (Wang et al., 2022) concluded that a smaller layer thickness promotes higher tensile strength because it promotes smaller interlayer spaces and, therefore, fewer air pores in the cross section.

(Johnson & French, 2018) analyzed the effect of filler density (15%, 30%, 50%, 50%, 90%, 100%) on the tensile response of different thermoplastics and concluded that 100% filler density obtained the highest tensile strength. Research conducted by (Kumar, Sridhar, Venkatraman, & Venkatesan, 2021) evaluated the effect of filler density on the tensile properties of Acrylonitrile styrene acrylate (ASA) and as a result obtained that a higher increase in filler density increases the tensile strength.

This research work aims to optimize the printing parameters to maximize the mechanical properties of PETG+CF. Attention will be paid to the stress effect to the model and the level of printing parameters, temperature, fill density, fill pattern, layer height and pattern orientation will be analyzed. The orientation of the printing pattern are important parameters in FFF printing due to the anisotropic nature of the printing and the layer by layer principle (Rashid & Koç, 2021). (Hsueh et al., 2021) tested different combinations of inclinations in the given directions in addition to the basic X, Y and Z orientations. surprisingly, samples printed at 60° with respect to X achieved the highest strength. (Letcher & Waytashek, 2014) stated in their work that the 45° orientation with respect to X is most advantageous, but in terms of ductility, it is the 90° orientation that achieves the highest accuracy of all orientations.

Carbon fiber-reinforced PETG polymer filament

Various plastic materials such as Acrylonitrile Styrene Butadiene (ABS), Polylactic Acid (PLA), NYLON, Polyethylene Terephthalate (PETG), etc. are used to manufacture parts in the FFF process, PETG is preferred for its excellent layer adhesion and relatively low cost. These properties have provided this material as a competitive alternative to other polymers such as ABS and PLA.

Filaments with improved mechanical properties were created, PETG has been filled with carbon fiber particles, this material is commonly referred to as PETG-CF. However, in PETG-CF is a plastic composite material that has an amorphous structure with a density of 1.38 g/cm3, a tensile strength of 55 to 75 MPa and a melting point of 2500 °C (Ajay Kumar, Khan, & Mishra, 2020). It is a mechanically strong, heat resistant, and solvent resistant material. It is odorless, tasteless and 100% recyclable. (Balderrama-Armendariz, MacDonald, Valadez, & Espalin, 2016) tested different thermoplastic materials for load carrying capacity under cyclic loading. The results show that PLA and NYLON materials can withstand smaller bending loads, while PETG can withstand loads of 800 cycles or more, with a bending angular displacement of 1800.

Regarding the traction to the PETG polymeric matrix, (Kasmi, Ginoux, Allaoui, & Alix, 2021) investigated the benefits achieved with continuous carbon fibers in PETG-based composites and found 9-fold and 17-fold improvements, respectively, for maximum tensile strength and tensile modulus compared to pure PETG. On the other hand, (Ferreira, Vale, Machado, & Lino, 2019) analyzed the effect of carbon fibers (20% by weight) as reinforcement of a PETG polymer and found improvements of 191.38% and 5.14%, respectively, for flexural modulus and strength, while tensile strength decreased by 28.1% but tensile modulus increased by 70.1%.

Methodology

This research adopts a general methodology as presented in Figure 4. The objective is to optimize the FFF printing parameters for mechanical stress resistances by applying the material polyethylene reinforced with carbon fiber (PETG-CF), with 80% polyethylene terephthalate and 20% carbon fiber, and the statistical part for process optimization will use the Taguchi method. SolidWorks software was used to make the design as shown in Figure 5, to build a static test model that complies with ASTM D638-22 type 1 (ASTM, 2022).

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The standard tessellation language (STL) format of sample designed and imported to the ideaMaker 4.1.1 Raise3D line software where the FFF process parameters are specified to subsequently perform a cut and obtain the G-code and import it to the FFF printer.

Tensile testing is one of the most widely used mechanical characterization techniques. This allows the determination of multiple standardized quantities used in structural calculations such as fracture toughness, maximum stress, etc. The Shimadzu AGS-X 100 KN is used as a tensile testing tool for 3D printed specimens. The machine is shown in Figure 6.

Box 4

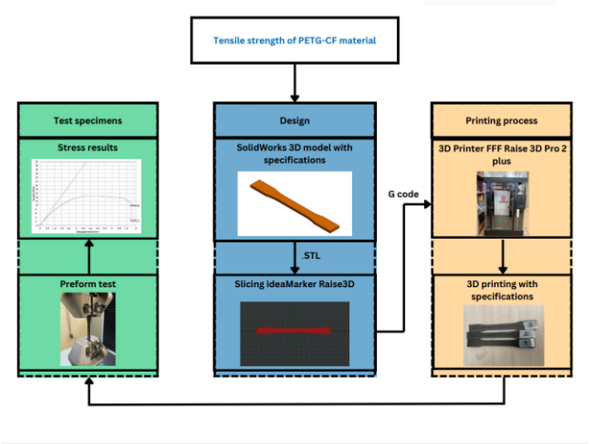

Figure 4
General methodology and study workflow

Box 5

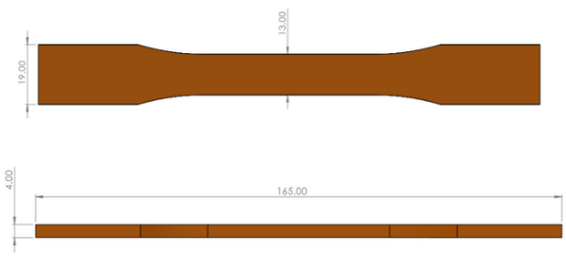

Figure 5
CAD model of ASTM D638 type 1

Box 6

Figure 6
Shimadzu AGS-X 100 K Tensioning machine

Experimental design (DOE)

To study FFF process parameters it is crucial to use systematic design of experiments (DOE) methods, such as Taguchi orthogonal design. These methods provide a structured and systematic approach to evaluate the effect of multiple input variables on a single output variable, allowing a more accurate characterization of the response surface and the identification of optimal configurations of the process parameters. The Taguchi method is a statistical method that uses an orthogonal matrix to design experiments and analyze results. This is useful for improving process robustness by identifying key factors that influence performance and determining the optimal levels of these factors. A pilot test was performed to determine various FFF printing parameters that influence the stress and strain of the 3D printed model. Accordingly, the printing parameters and their range that have been considered are the infill pattern, which varies between lines, triangle, honeycomb and gyroid, and infill density between 25 to 100 % with steps of 25%, layer height from 0.3 mm to 0.15 mm, nozzle temperature from 245 °C to 260 °C with steps of 5 °C, raster orientation θ from 0° to 90° with steps of 30 ° as shown in Table 1. Table 2 shows the parameters that will be fixed at all levels, the parameters were selected as specified by the manufacturer.

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The experimental design will be carried out using Taguchi's orthogonal matrix method, where the total number of experiments can be reduced and statically obtain the same valid result as if using the 4 X^5 factorial design. The degree of freedom (DOF) is obtained by subtracting 1 from the number of levels. The degree of freedom for each factor with 4 levels will be 3. Therefore, the total degree of freedom for 5 factors with 4 levels will be 15. Table 3 includes the experimental design of the selected FFF manufacturing parameters for this experiment.

For experimental purposes the Taguchi method involves the optimization of process parameters by means of a robust experimental design. The signal-to-noise ratio is a quality parameter used to evaluate the effect of input factors on the responses. In the current research study, all output responses are quality characteristics of the type bigger is better, the goal of the experiment is to maximize the response. To evaluate the S/N ratios, the type of quality features, the bigger is better, shown in Equation 1 has been used.

$$\frac{S}{N} = -10\ log\ (\Sigma \frac{\frac{1}{Y^2}}{n}) \quad [1]$$

Box 7

Table 1

FFF print control parameters with 4 levels each.
T= Triangle, H= Honeycomb, G= Gyroid, L= Lines

Parameters	Level 1	Level 2	Level 3	Level 4
Filling pattern	T	H	G	L
Nozzle temp (°C)	245	250	255	260
Part orientation (θ)	0	30	60	90
Layer Height (mm)	0,3	0,25	0,2	0,15
Filling density (%)	25	50	75	100

Box 8

Table 2

Fixed FFF print control parameters

Parameters	Value
Bed temperature	100 °C
Printing speed	50mm/s
Build plate adhesive type	Brim
Infill overlap porcentage	100%
Fan speed	50%
Infill layer thickness	0,1 mm
Wall thickness	0,8 mm

Box 9

Table 3

Experimental design of the FFF print parameters using the orthogonal matrix L_{16}.
(EXP)= Experiment, (F.P)= Filling pattern, (TEMP)= Temperature (°C), (P.O)=Part orientation (θ), (L.H)= Layer height (mm), (F.D)= Filling density (%).

EXP.	F.P	TEMP	P.O	L.H	F.D
1	T	245	0	0,30	25
2	T	250	30	0,25	50
3	T	255	60	0,20	75
4	T	260	90	0,15	100
5	P	245	30	0,20	100
6	P	250	0	0,15	75
7	P	255	90	0,30	50
8	P	260	60	0,25	25
9	G	245	60	0,15	50
10	G	250	90	0,20	25
11	G	255	0	0,25	100
12	G	260	30	0,30	75
13	L	245	90	0,25	75
14	L	250	60	0,30	100
15	L	255	30	0,15	25
16	L	260	0	0,20	50

Experimental 3D printing FFF

The G-code files obtained from the cutting software were used to fabricate samples using a FFF Raise3D Pro2 Plus printer with print dimensions 305x305x605 mm, nozzle diameter 0.4 mm. Carbon fiber reinforced polyethylene terephthalate (PETG-CF) material of 1.75 mm filament diameter was used in this study. The four fill patterns that were defined for the experimental tests were (Triangle, Honeycomb, lines, gyroid) with fill densities of; 25, 50, 75 and 100 %, along with the parameters mentioned in the Taguchi design of experiment. Then, the models are printed accordingly. A standard based tensile testing machine (brand) is used, in this case study ASTM D638-22 is used to perform the tensile tests, and take the tensile measurement of each specimen.

Results

Modeling and printing of ASTM D638-22 specimens

The 3D model of the specimen as shown in Figure 5, is generated from the instructions and dimensional tables stipulated in the standard (ASTM, 2022) using SolidWorks CAD software and then exported to the STL file format. Obtaining the STL file the model is divided into individual layers and converts the STL into G-code using the ideaMaker 4.1.1 Raise3D slicer, Figure 7.

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The G-code makes the 3D printer tools move according to the layer information generated during the slicing process. Therefore, a total of 16 models are printed, as stipulated by the DOE and shown in Figure 8.

Box 10

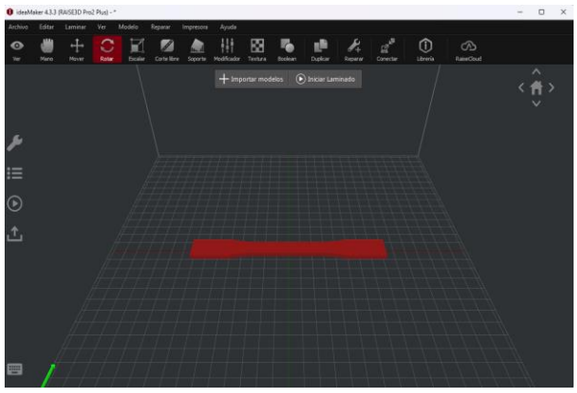


Figure 7
ASTM D638 models on the ideaMaker 4.1.1 Raise3D slicer.

Box 11

Figure 8
ASTM D638 models printed on FFF with PETG-CF according to DOE orthogonal array L_{16}

Tensile testing

Samples were loaded at a speed of 2 mm/min. All tests were performed at room temperature and repeated three times to ensure repeatable results. Tests are performed on dumbbell shaped specimens under aesthetic tensile testing for the different filler patterns lines, triangle, honeycomb and gyroid at different filler densities 25%, 50%, 75% and 100%.

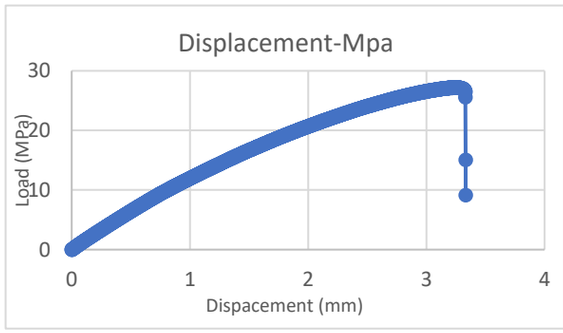
Other parameters, temperature, build angle and layer height, which are important for tensile testing, are also taken into account. Figure 9 shows how the specimen is clamped in the tension machine.

Box 12

Figure 9
Tensioning machine performing tensile work on specimen

The results were recorded, 16 tensile tests were performed on specimens to examine the mechanical behavior of the carbon fiber reinforced PETG material manufactured by the FFF process. Due to the experimental test results we can see a complete characterization of the material used to record other parameters such as displacement, strain length, face and transverse. The test results show that the mechanical behavior of the material is elastic plastic. Graph 1 shows the force-displacement curve of specimen number 4 with 27.19 MPa and with the following parameters; fill pattern "triangle", nozzle temperature 260° C, frame orientation 90°, layer height 0.15 mm, fill density 100%.

Box 13



Graphic 1
Probe displacement force curves 4

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Damage mechanisms in specimens

Figure 10 shows all the specimens that were analyzed after fracture. Most of the polymer ruptures are ductile due to reorientation and stretching of the plastic into filaments, which causes the material to deform considerably.

Box 14

Figure 10
The breakage specimens after tensile test

By observing the results of specimen rupture occurred in different sections of the specimens analyzed at the end of the tensile test. The parameters selected for each specimen were different and certain factors of them influence the zone where it breaks in the specimens. Table 4 shows the tensile results of the 3D printed specimens.

Box 15

Table 4
Tensile results of specimens
(MPa)= Megapascals

EXP.	F.P	TEMP	P.O	L.H	F.D	MPa
1	T	245	0	0,30	25	15.94
2	T	250	30	0,25	50	24.46
3	T	255	60	0,20	75	24.66
4	T	260	90	0,15	100	27.19
5	H	245	30	0,20	100	23.20
6	H	250	0	0,15	75	19.45
7	H	255	90	0,30	50	18.28
8	H	260	60	0,25	25	17.65
9	G	245	60	0,15	50	17.38
10	G	250	90	0,20	25	15.50
11	G	255	0	0,25	100	22.94
12	G	260	30	0,30	75	21.65
13	L	245	90	0,25	75	18.29
14	L	250	60	0,30	100	26.58
15	L	255	30	0,15	25	13.94
16	L	260	0	0,20	50	15.98

Optimization of printing parameters for tensile stress strengths

Mentioned in the methodology to obtain a printed model with greater resistance to stress, the Taguchi characteristic "Bigger is better" is taken into consideration, whose value is obtained by means of formula 1. The signal-to-noise ratio (S/N) for each level based on the largest-is-best characteristic is shown in Table 5 which represents the optimum parameter, that is the parameter with the highest S/N ratio to minimize the absolute variation and the impact of each element set in the delta value. Therefore, according to the values mentioned in Table 5, and the graphs in Figure 11. The optimum parameter for higher strength and is when the triangular fill pattern, the nozzle temperature is 250° C, the weft orientation is 60°, the layer height of 0.30 mm and the fill density is 100%.

Box 16

Table 5
Response for signal to noise ratios (S-N)

LEVEL	F.P	TEMP	P.O	L.H	F.D
1	26.56	25.36	25.26	26.06	23.94
2	25.74	26.20	25.91	26.00	25.11
3	25.59	25.40	26.23	25.47	26.11
4	25.17	26.10	25.66	25.53	27.90
Delta	1.39	0.84	0.97	0.59	3.95
Range	2	4	3	5	1

Box 17

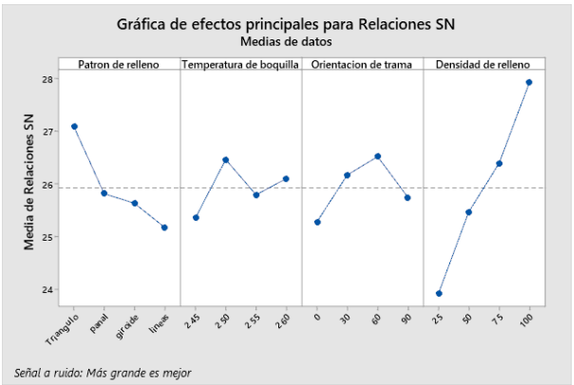

Figure 11
Main effects plot for ratios (S/N)

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The data is further analyzed using ANOVA which result is shown in Table 6. It can be observed that the p-values of infill density and infill pattern are significant values as their values are very close to 0; this indicates that the two mentioned parameters are very significant in relation to the stress resistance of the 3D printed models. Infill density has the highest contribution of 178.404 with respect to strength improvement, followed with infill pattern with 45.809, the remaining parameters contain in their high p-value which makes them insignificant in the response variable, this suggests that changes in the predictor are not associated with changes in the response. The next contribution value is plot orientation with 20.103. In addition, regression analysis is performed on the data set which determines the coefficient, R-value^2 of 98.18%.

Box 18

Table 6

Table of ANOVA results

SOURCE	GL	SC Sec.	SC Ajust	MC Ajust	F	P
P.R	3	45.809	45.809	15.270	9.46	0.049
TEMP	3	16.641	16.641	5.547	3.44	0.169
O.T	3	20.103	20.103	6.701	4.15	0.136
D.R	3	178.404	178.404	59.468	36.84	0.007
ERROR	3	4.842	4.842	4.842		
TOTAL	15	265.799				

Figure 12 shows the normal probability plot, in which the standard residual value is within the acceptable range of ± 0.8, indicating that there is no delineator in these data.

Box 19

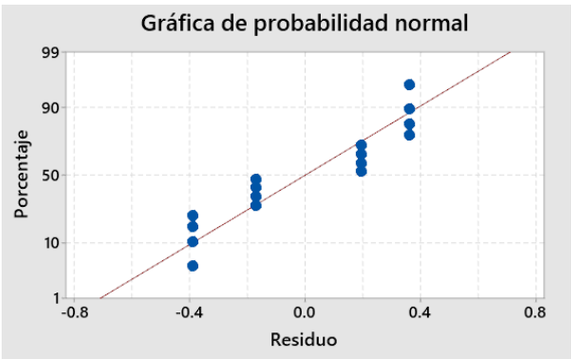

Figure 12

Normal probability plot

Validation of the result

The density of the filler greatly influences the tensile strength of the specimens using the PETG-CF material as shown in the ANOVA analysis in Table 6. The optimum strength is achieved when the filler density is 100%, it can be observed that the stresses increase the higher the percentage of build density the 3D print has as seen in the S/N mean plot shown in Figure 11.

(Daly, Tarfaoui, Chihi, & Bouraoui, 2024) conducted an experimental study where they examined the responses of PETG-CF samples with the same densities used for this study (25%, 50%, 75% and 100%) under different impact pressures resulting in 2.4 bar of pressure with 100% density, the higher the filler density the stronger the 3D printed component. Among the four types of infill that were selected, the infill pattern with the highest finding is the triangular one, which is similar to the result from (Alafaghani, Qattawi, Alrawi, & Guzman, 2017) The optimum printing temperature for tensile strength is observed at 250°C the findings of. (Valvez, Silva, & Reis, 2022) aligned with the PETG-CF study where the optimum temperature was 250°C. the literature reports that the nozzle temperature consequent to viscosity and printing speed are related and should be analyzed (Abeykoon, Sri-Amphorn, & Fernando, 2020) but in this study printing speed was not used as a parameter. The raster angle or also known as the build angle is defined as the way the part is oriented on a build platform with respect to the X, Y and Z axes. In certain articles, build orientation represented a quantitative parameter.

(Raju, Gupta, Bhanot, & Sharma, 2019), but in others, it was considered as a categorical parameter. (Jesus Miguel Chacón, Caminero, García-Plaza, & Núnez, 2017) The raster orientation shows reduction of surface roughness. (Anitha, Arunachalam, & Radhakrishnan, 2001; Raju et al., 2019) and cataloged that the parameter is significant for surface quality, however, also (Alafaghani et al., 2017) examined the impact of the build orientation parameter as a significant parameter for dimensional accuracy. In this work, this parameter was studied to observe the importance of print orientation on part strength and determine its significant value as an important parameter in tensile strength.

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Optimal printing parameters

The optimum 3D printing parameter obtained by Taguchi's method with higher characteristic shown in Table 7.

Box

Table 7

Optimal printing parameters with respect to tensile strength

F.P	TEMP	P.O	L.H	F.D
T	250	60	0,30	100

Conclusions

The development of a new PETG-CF composite material by additive manufacturing through experimental testing was successful. The results from exploratory testing and literature are closely correlated, showing that this material is suitable for a variety of applications. This material could benefit multiple industries as it combines strength and durability. The summary of research findings is broken down below.

This work focuses on the optimization of important tensile strength-oriented printing parameters, namely, fill density, fill pattern, nozzle temperature, build orientation and layer height were used to optimize the printing parameters of components using PETG-CF material. The selection of parameters of specimen prints was according to the orthogonal array experimental design L_{16}. The observed results are shown below:

- Using the "bigger is better" characteristic of the Taguchi method, the maximum tensile stress was observed when the fill density is 100%; the fill pattern is triangular; the weft orientation is 60°; the nozzle temperature is 250°C; the layer height is 0.3mm.

- ANOVA analysis of the data has shown that 4 of the selected parameters are quite influential and significant for tensile strength as their p-value is very close to 0. Tensile strength was highly influenced by filler density with a contribution of 178.404, followed by filler pattern with a contribution of 45.809.

The present research work focused solely on the optimization of parameters to the tensile strength of PETG-CF in FFF. Future studies could investigate optimal printing parameters of FFF with multiple targets at compressive strength and shorten the time required for printing while maintaining it at the tensile strength of the model using complex geometries. This work could help to produce good strength material and dimensionally accurate models with shorter printing time.

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

In this study, we conducted a comprehensive investigation on the printing optimization of carbon fiber reinforced thermoplastic polymer (CF-PETG) produced by fused filament fabrication (FFF). We performed static tensile tests on dumbbell-shaped samples, considering honeycomb, line, triangle and gyroid fill patterns, at various fill densities (20 %, 50 %, 75 % and 100 %), nozzle temperature, part orientation and layer height. To ensure accuracy, we employed the Shimadzu AGS-X 100 K test apparatus, maintaining a constant travel speed of 2.5 mm per minute. Our experimental findings showed that the mechanical behavior of each sample exhibited elastoplastic characteristics. In particular, the triangle-shaped pattern exhibited superior strength and stiffness compared to the rectilinear pattern. The Taguchi experimental design with an L16 orthogonal array was used for parameter optimization. The review followed the recommendations of the tutors, ensuring the validity and rigor of our findings.

J. Alan Martinez Cervantes: Formal analysis, methodology, and writing-original draft.

Luis Javier Sanchez: Formal analysis, project administration and editing corrections.

Julian I. Aguilar Duque: Methodology, project administration and research method.

All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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Abbreviations

3D	Three dimension
ASTM	American Society for Testing and Materials
ABS	Acrylonitrile butadiene styrene
AM	Additive manufacturing
CAD	Computerized-aided design
PETG-CF	Polyethylene Tetra Glycol reinforced with carbon fiber.
EXP	Experiment
F.D	Filling density
L.H	Layer Height
PLA	Polylactic acid
P.O	Part orientation
S/N	Signal to noise
STL	StereoLithography
TEMP	Temperature

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Differences

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Article

Thermal-structural numerical analysis of the brake and disc system of a Formula SAE 2024 type vehicle

Análisis numérico térmico-estructural del sistema de frenos y disco de un Formula SAE 2024

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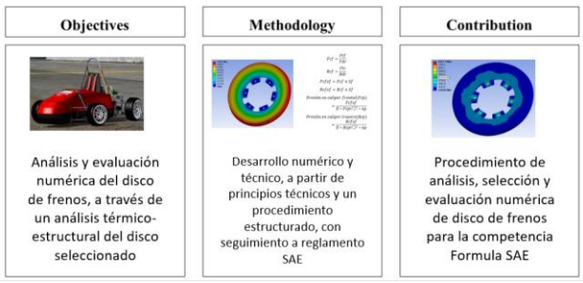
Abstract

The results of the numerical evaluation process of the brake and disc system of a Formula SAE type vehicle in its 2024 version are presented. Through the process of evaluating fundamental equations for the brake system, the type of disc and its properties are selected. physical. Using finite element analysis based on a thermal-structural evaluation, disc operating parameters are evaluated, which in comparison with those presented by other competitors in the Formula SAE competition, show similar numbers in the performance expected by the brake system and in particular of the disc considered in the design of the vehicle.



Formula SAE, Thermal-structural analysis, Brake disc

Resumen

Se presentan los resultados del proceso de evaluación numérica del sistema de frenos y disco de un vehículo tipo Formula SAE en su versión 2024. A través del proceso de valoración de ecuaciones fundamentales para el sistema de frenos, se selecciona el tipo de disco y sus propiedades físicas. Empleando análisis por elementos finitos basados en una evaluación térmico-estructural, se evalúan parámetros de operación del disco, los cuales en comparación con los presentados por otros competidores en la competencia Formula SAE, muestran números similares en el desempeño esperado por el sistema de frenos y en particular del disco considerado en el diseño del vehículo.

Formula SAE, Análisis térmico-estructural, Disco de frenos

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Introduction

Formula SAE is a series of competitions in which different teams of undergraduate and graduate university students compete to design, build, test and promote a prototype racing car that meets strict regulations (Vechiato et al., 2024). Its fundamental goal is to provide participants with hands-on experience in design, manufacturing and team collaboration, while promoting innovation and creativity in the field of automotive engineering. Each year, hundreds of teams from universities and technical colleges compete in regional and global events, putting their vehicles through a series of static and dynamic tests that evaluate both the design and performance of the car. Today, Formula SAE has established itself as one of the most prominent competitions for engineering students in the automotive field. As an important part of the race car chassis, the braking system assumes responsibility for ensuring driver safety and directly affects the handling of the race car. Therefore, the design of the race car brake system is especially important (Chen & Huang, 2022).

Brakes are used to stop the motion of the moving vehicle or control its speed. They are required to stop the vehicle in the shortest possible distance, and they do so by converting the kinetic energy of the vehicle into thermal energy through friction. The frictional forces produced between the road and the tyre are induced by the brake to stop, control and prevent movement. The braking system must be efficient and effective for the vehicle as it must not disturb the comfort of the driver when applying pedal effort. It should create sufficient deceleration to stop the vehicle as soon as the pedal is pressed forward, with minimal effort and friction, which causes heat to dissipate effectively into the surrounding atmosphere (Tawhare & Kulkarni, 2021).

In addition to their role in safety and performance, brake discs also influence the overall vehicle design. Their weight and distribution affect the dynamics of the car, impacting its handling, stability and agility on the track.

Within the components of the braking area, the pedal has specific operational requirements for its operation by regulation and essential system operation, which when fulfilled have been subject to optimisation in order to have a light and resistant component that fulfils the braking function, but seeking to add the least amount of mass to the final vehicle (Cordero et al., 2023). Sizing the braking system is fundamental in the design and assembly process of the project. From it, it is possible to analyse feasibility parameters of the braking system and better understand how the vehicle works during braking (de Farias Gomes, 2022).

Different studies have been carried out to evaluate the requirements of the brake disc for the Formula SAE competition, in a first category there are studies where the design and verification of the brake disc have been developed, together with methodologies for the validation of both for their application in vehicles. In the work presented by de Farias Gomes, T. (2022), the sizing process of a braking system for a Formula SAE vehicle was developed, based on the analytical evaluation of the braking forces based on the mechanical properties of the vehicle presented, restricting the study to only the evaluation and respective calculations. In another study, Umesh & Rupesh (2022) presented the respective calculations for the evaluation of the braking forces and pressure values required in the brake disc for a Formula SAE vehicle, based on these data they present the structural and thermal evaluation of the brake disc, restricting their numerical evaluation to the disc only. Reddy et al. (2013), in their study related to the modelling and analysis of a Formula SAE vehicle brake disc, present the results of the disc modelling and FEA evaluation of the disc, including structural and thermal evaluation results, adding in their study the evaluation of different materials for validation and comparison.

Description of the method

The work presented was based on a step-by-step process, which started with the general system information from previous years, followed by the analytical evaluation of the system and then, with the global information on the technical requirements, the brake disc analysis was developed. The totality of the steps developed are shown in Figure 1.

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Box 1

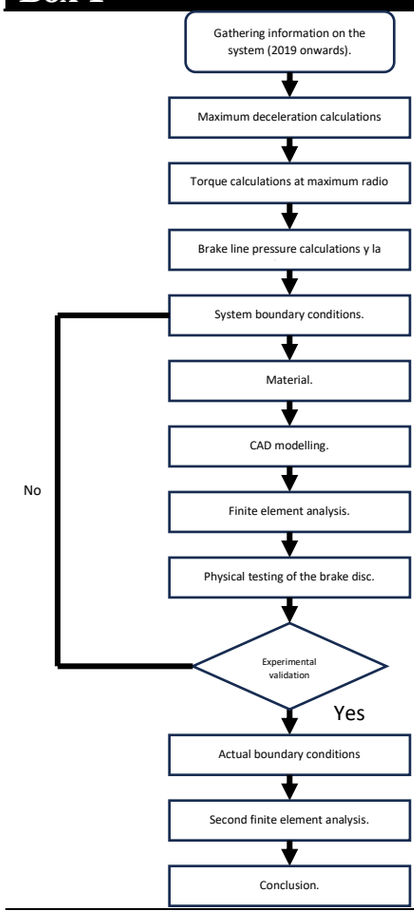

Figure 1

Numerical evaluation process of the Formula SAE braking system

Source: Own elaboration

Analytical description of braking properties

It was decided to use the most representative equations, which were the basis for the analysis of the brake discs, and which are reflected in the final results, but the results are explained graphically and in writing.

Initially, we will evaluate the coefficient of friction with respect to the ground.

The coefficient of friction

Caliper piston surface = SPC
Effective disc radius = RE_D
Brake torque = TF
Fluid pressure = PF

$$\frac{1}{2x\ SPC\ (cm^2) x RE_D\ (m)} x \frac{TF\ (kgf \cdot m)}{PF\ (kgf/cm^2)} \quad [1]$$

Centre of gravity summation

As we have both axes, we will have to add them together to get the battle.

$$(CG_{d,x}) = \frac{P_t}{P} \cdot L$$

$$(CG_{d,x}) = \frac{P_d}{P} \cdot L$$

$$CG_{d,x} + CG_{t,x} = L \quad [2]$$

Weight transfer

To determine the weight transfer, we first need to find the weight on each axle.

Weight at the front and rear:

$$Wf = percentage\ of\ front\ weight * W$$
$$Wr = percentage\ of\ rear\ weight * W$$

Wheelbase (front and rear)):

$$Lf = \frac{Wr*L}{W} \quad Lr = \frac{Wf*L}{W} \quad [3]$$

Front and rear axle weight:

$$Wfb = W * \frac{Lr + (utr * HCG)}{L + (utr - utf) * Hcg} \qquad Wrb = W * \frac{Lr + (utf * HCG)}{L + (utr - utf) * Hcg}$$

Axle weights with aerodynamic loading:

$$Wfb\ aero = Wfb + frontal\ downforce$$
$$Wrb\ aero = Wrb + rear\ downforce$$

Weight transfer:

$$Wtf = Wfb\ aero - Wrb\ aero$$

Percentage of weights:

$$Wfp = \frac{Wfb}{Wfb+Wrb} \qquad Wrp = \frac{Wrb}{Wfb+Wrb} \quad [4]$$

Braking torque front axle

To find the braking torque, it must be obtained from the braking force and the effective tyre radius.

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$$(N_d) = F_{F,d} \cdot R_d = \mu \cdot [P_d + (\frac{a_{fv}}{g}) \cdot (\frac{H_{CG}}{L}) \cdot P] \cdot R_{n,d} \quad [5]$$

Braking torque rear axle

$$(N_t) = F_{F,t} \cdot R_t = \mu \cdot \left[P_d + \left(\frac{a_{fv}}{g}\right) \cdot \left(\frac{H_{CG}}{L}\right) \cdot P\right] \cdot R_{n,d} \quad [6]$$

Braking efficiency

Finally, to find the braking efficiency we have to divide the braking force of each axle by the dynamic weight of each axle.

$$\frac{F_{F,d}}{P_{d,f}} = \frac{F_{F,t}}{P_{t,f}} \quad [7]$$

Braking Torque and Brake Disc Radius Calculations

Braking torque specifies the amount of torque required to stop the rotation of the tyre and thus bring the tyre into a locked condition. The disc radius helps to quantify the amount of clamping force each caliper will generate, the larger the radius, the smaller the clamping force.

$$Nt = \frac{(w \times \phi) \pm Wt}{2}$$

$$(Brake\ Torque)\mu p \times C \times Rd = \mu \times Nt \times R \quad [8]$$

Brake force

Knowing the braking force on each caliper will allow us to choose the type of caliper required for the front and rear wheels. The safety factor (Sf) will allow the locking of the rims which is a requirement of the regulations (Fcf = Front Caliper Force and Rcf = Rear Caliper Force, Fcfsf = Front Caliper Force With Safety Factor, Rcfsf=Rear Caliper Force With Safety Factor,s, Fcpr=front caliper piston radius, Rcpr=rear caliper piston radius, Rcpr=rear caliper piston radius, Fcpr=rear caliper force with safety factor).

$$Fcf = \frac{Ftf}{Fdr}$$

$$Rcf = \frac{Ftr}{Rdr}$$

$$Fcfsf = Fcf \times Sf$$

$$Rcfsf = Rcf \times Sf$$

$$Front\ caliper\ pressure(Fcp) = \frac{Fcfsf}{\Pi * Fcpr^{\ 2} * np}$$

$$Rear\ caliper\ pressure(Rcp) = \frac{Rcfsf}{\Pi * Rcpr^{\ 2} * np} \quad [9]$$

Box 2

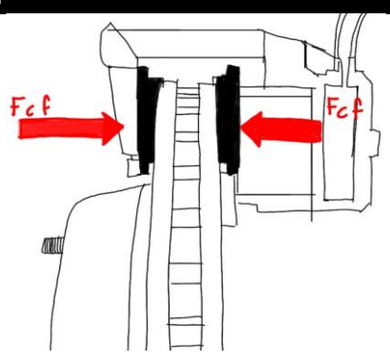

Figure 2
Distribution of forces on the disc
Source: Own elaboration

Master cylinder force

Fmcf=Front master cylinder force, Fmcd=Front master cylinder bore, Rmcf=Rear master cylinder force, Rmcd=Rear master cylinder bore

$$Fmcf = Fcp * (\frac{Fmcd}{2}^{\ 2} * \Pi)$$

$$Rmcf = Rcp * (\frac{Rmcd}{2}^{\ 2} * \Pi) \quad [10]$$

Brake disc diameter

Pft=rear braking torque, pfd=front braking torque, Ffmax=max braking force.

$$D = \frac{(pft+pfd)}{Ffmax} \quad [11]$$

Description of general vehicle properties

Currently the vehicle design already has a body and a Formula SAE type design of the year 2023, the general design is shown in figures 3 and 4.

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Box 3

Figure 3

General design of the Formula SAE 2023 type vehicle.
Source: Own elaboration

Box 4

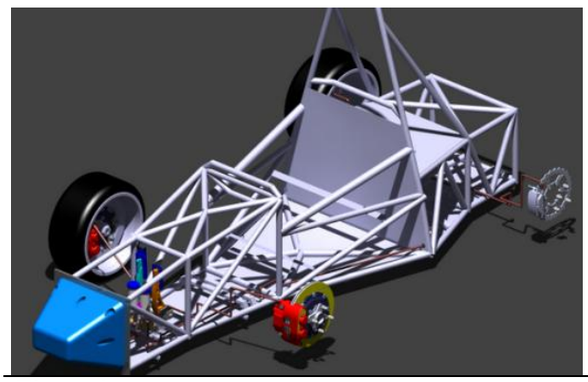

Figure 4

SAE 2023 Formula 2023 vehicle structure design
Source: Own elaboration

In addition, we have as a basis the following characteristic,mns that we consider important to take into account for the following proposal for the new 2024 body. The data are shown in table 1.

Box 5

Table 1

Formula 2023 vehicle properties

Property	Value	Unit
Length	1900	mm
Width	900	mm
Height	600	mm
Weight	235	kg
Area	19.618	m2

Source: Own elaboration

Development

General configuration of the SAE brake system

Based on previous design proposals and typical system considerations, a configuration of 4 brake discs (one per wheel rim) and a hydraulic system was chosen. Figure 5 shows a graphical description of the type of system proposed.

Box 6

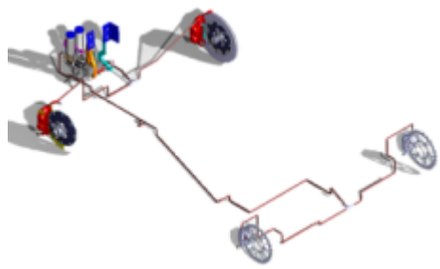

Figure 5

Graphical depiction of the overall braking system for a Formula 2024 type vehicle

Source: Own elaboration

Development and selection of brake discs

For the selection of the brake discs for the Formula SAE vehicle, various calculations were carried out in order to determine which ones would be the right choice.

In Formula SAE competitions, the design and optimisation of the brake discs is critical to ensure optimum and safe vehicle performance. To achieve this, a series of data was used to enable us to calculate key aspects related to braking and weight distribution.

For the basic Formula vehicle data we set the tyre radius at 0.2482m, followed by using the gravity value of 9.81m/s2, and a calculated tyre height of 0.2286m.

The first fundamental data we use refers to the wheelbase, taken as 1.52908 m. Using the size of the car as a reference, the front and rear axle weight distribution was 34.82% and 65.18% respectively. While, the centre of gravity distances to the front and rear axles were 100 mm and 53.43 mm.

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In addition, we employed deceleration equations based on Newton's second law. By solving this equation, we can determine the negative acceleration, which is essential for calculating the braking distance of the vehicle. This distance is calculated by taking into account the vehicle speed and the negative acceleration, which gives us a rough estimate of the distance needed to stop the vehicle in various situations.

To better understand the weight distribution between axles, we use equations that allow us to calculate the weight force on the front and rear axle. By knowing the weight applied to each axle and the total weight of the vehicle, we can determine the force distribution on each axle, which directly influences the braking ability and stability of the vehicle.

Additionally, the normal force was calculated with a result of 2336.1141 N. On the other hand, the axle normal forces were determined with 813.5213 N. and 1522.5928 N.

Finally for the effects on the vehicle due to deceleration (TP) was calculated as 523.8794 N, and the applied forces on the front and rear axles are 1337.4007 N. and 998.7133 N.

Box 7

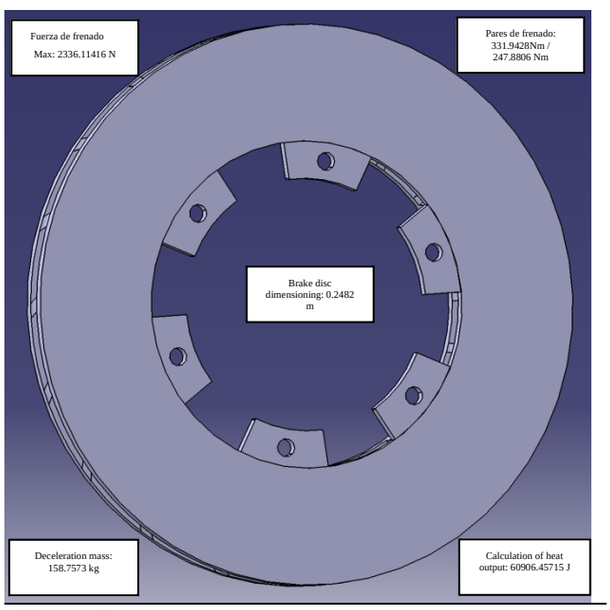

Figure 6
Technical capabilities of the brake disc
Source: Own elaboration

Braking force and selection of corresponding accessories

In this research, equations were used to analyse the weight transfer at the front and rear axles, as well as the braking force, braking torque and braking force efficiency, in order to select the most suitable brake discs and brake calipers.

Equations [3] to [9] based on principles of vehicle dynamics and braking mechanics were used to calculate the weight transfer at the front and rear axles, the braking force at each axle, the braking torque and the braking force efficiency. These equations considered factors such as vehicle mass, brake system geometry, load distribution, among others.

The results of the calculations showed a weight transfer of 49% to the front axle during braking, indicating the need for increased braking capacity on this axle. The braking force required at the front axle was 109 N, while at the rear axle it was 204 N. The braking torque required to stop the vehicle under maximum load conditions was determined to be 84 Nm. In addition, a brake force efficiency of 170% was calculated.

Brake disc

For the selection of the brake discs, pads and calipers, we found that they should be 248mm. Since these sizes would have to be custom-made and the intention is to use existing models that are available on the Mexican market, it was decided to choose standard discs with a diameter of 200 mm and a width of 12 mm, for the front and rear wheels respectively.

As for the caliper size, we obtained as a result that a caliper with 223.44647 kPa of pressure is needed for the front calipers and 542.34077 kPa of pressure for the rear calipers, including a safety factor of 2. To determine which caliper will be used, the piston area of the front and rear calipers was determined, obtaining 2026.8299 mm^2 and 1013.41495 mm^2 respectively. In the accessories section, for the selection of the master cylinders (equation 8), the necessary force was calculated from the pressures obtained from the calipers (equation 8), resulting in 110.90047 N for the front cylinder and 217.0717 N for the rear cylinder.

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Two different ones will be used as the Formula SAE 2024 regulations require the division of two individual circuits of the brake system, in this case front and rear.

To determine whether a servomotor will be required for the brake pedal, the force required to operate the pedal was determined and we obtained a force of 140.69 N, which means that the inclusion of the assistance system will not be necessary.

Disc analysis

With the data we have obtained by means of calculations, we have obtained that our brake disc must have a diameter of approximately 177.47 ml, the effective braking area, which is obtained based on the maximum braking torque and pressure, is 49476.27 m^2 and was obtained based on the thermal energy generated, the heat capacity and the mass of the disc.

Based on the data obtained, we determined that the K238SS-200 disc of the Righetti Ridolfi brand is the right choice for our vehicle, since it has the characteristics sought and which are valid in the current Formula SAE regulations. It has the following characteristics described in Table 2:

Box 8

Table 2

Characteristics of the selected brake disc

Property
'Vented Brake Disk 200x12mm Grooved'.
Cast iron
Outer diameter 200 mm
Thickness 12 mm / 6 holes: 6,5 mm
Wheelbase holes 114 mm

Source: Own elaboration

To give validity and support to our calculations, it was decided to carry out thermal-structural and modal studies of the chosen disc.

Box 9

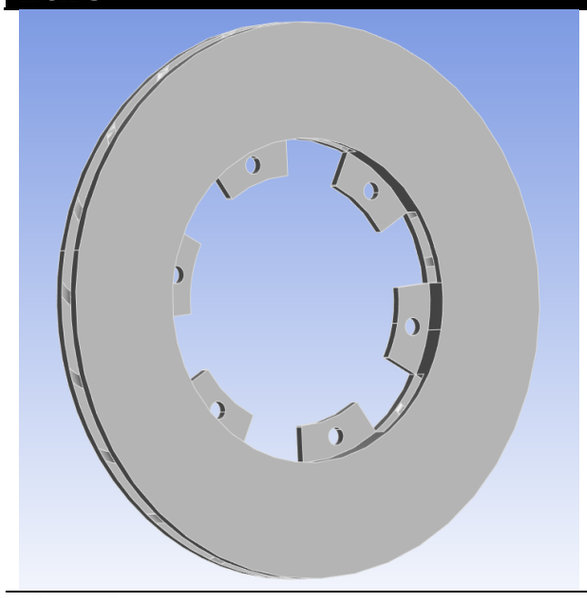

Figure 7

CAD model used for numerical brake disc analysis

Source: Own elaboration

For the analysis, a finite element model was developed, which had the following properties described in Table 3:

Box 10

Table 3

2023 Finite element model properties

Analysis	Modal	Structural Static
Size of elements	4	4
Type of elements	tetrahedra	tetrahedra
Number of mesh elements	55960	55960
Element quality	5e-002	5e-002
Analysis	Modal	Structural Static

Source: Own elaboration

Thermal study of brake discs

In the evaluation process of the selected disc, brake disc operating conditions were considered and applied to the brake disc, as shown in figures 8 and 9.

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Box 11

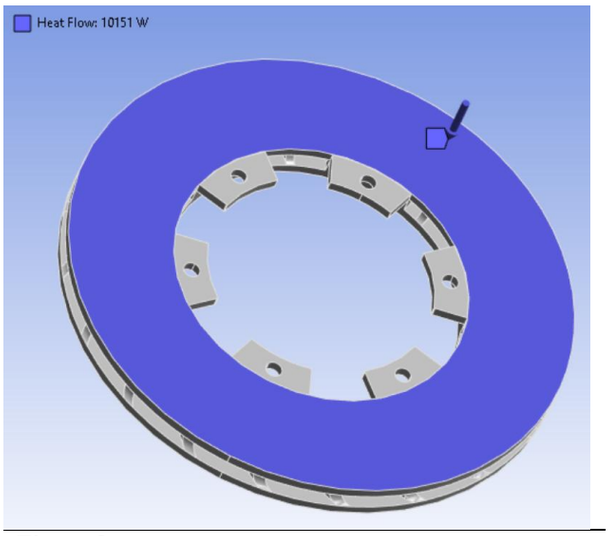

Figure 8
Thermal flux on the outer sides of the disc
Source: Own elaboration

Box 12

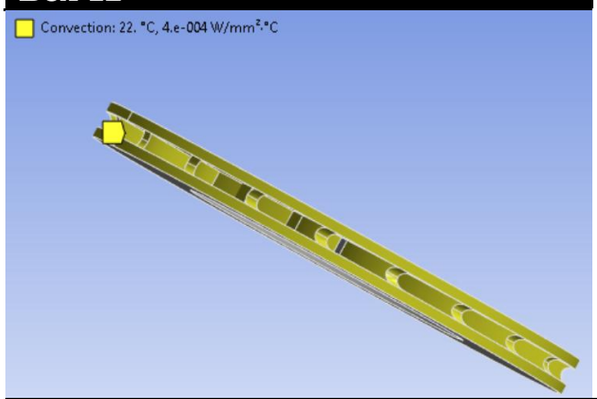

Figure 9
Convection on the inner sides of the disc
Source: Own elaboration

Figure 10 shows the results of the maximum temperatures reached generated by an ambient temperature of 22°C and a brake heat output of 10,151.07619 watts.

Box 13

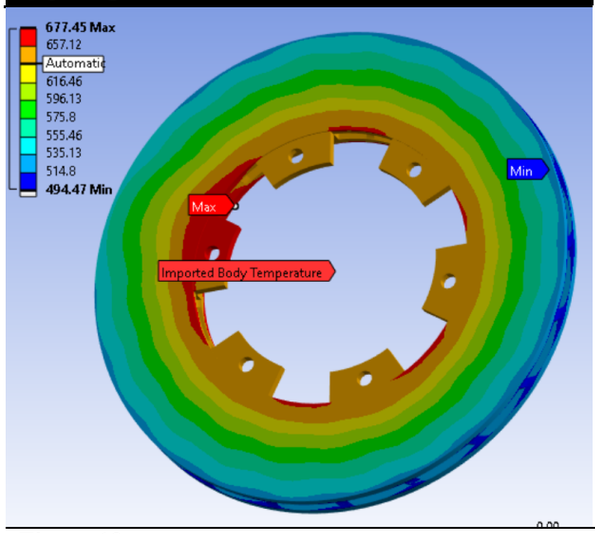

Figure 10
Brake disc temperature distribution
Source: Own elaboration

Static thermal-structural study of brake discs

The pressure applied to the disc was 331.94 N/m on the outer faces as shown in figure 11.

Box 14

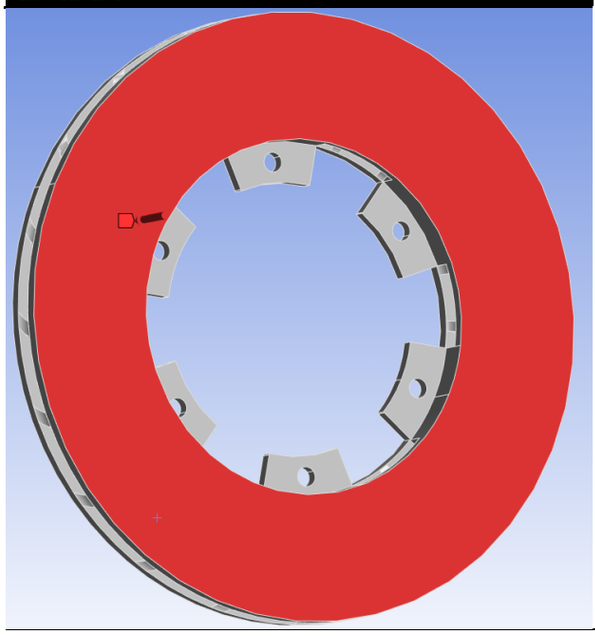

Figure 11
Pressure loads on the outer faces of the disc.
Source: Own elaboration

Based on the pressure used and the fastening in the bolt holes and their attachment to the brake system, in addition to the initial conditions of the temperature distribution, a total deformation of 1.0075 mm generated by the pressure was obtained, with the distribution shown in figure 12.

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Box 15

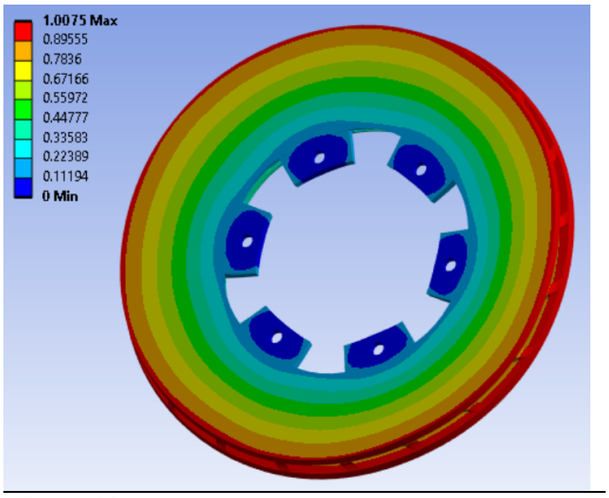

Figure 12

Total deformation of the brake disc

Source: Own elaboration

From the thermal-structural evaluation, the equivalent stress of the Von Mises criterion was obtained with a maximum of 6521.3 Pa, as shown in figure 13.

Box 16

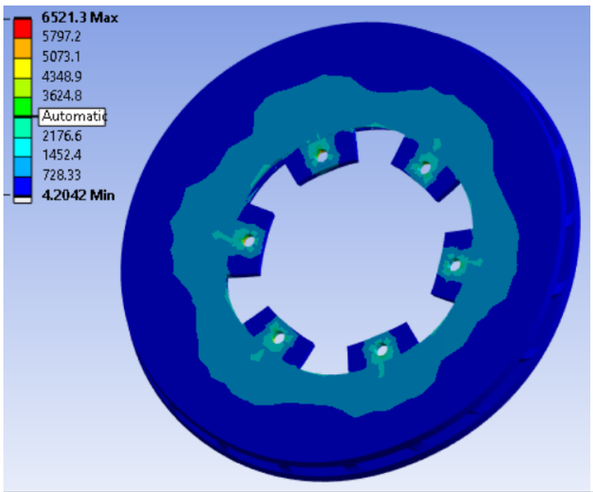

Figure 13

Structural thermal stress (Von-mises equivalent stress)

Source: Own elaboration

Modal analysis with thermal preload

Based on the fastening of the screws, a frequency study was carried out on the disc, which yielded the following results. Table 4 and figure 14 show the results of the vibration modes..

Box 17

Table 4

Comparison of modal analysis results

Mode	Thermal modal (Hz)	Max. total deflection. (mm)	Total deflection min.
(mm)			
1	0	34.953	19.239
2	0	34.364	16.441
3	0	46.811	7.3421
4	4.602e-003	36.508	18.251
5	4.877e-003	39.612	5.6404
6	5.2622e-003	44.325	1.6614

Source: Own elaboration

Box 18

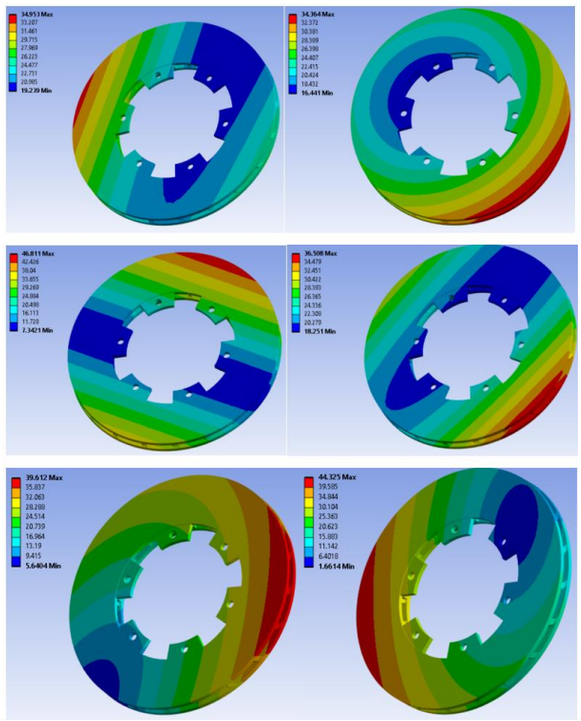

Figure 14

Modal analysis with thermal pre-load

Source: Own elaboration

Analysis results

For the analysis of the disc, a CAD was modelled with the characteristics closest to the real model. Made of cast iron.

Structural and thermal results were obtained from the conjugate analysis, which are shown in table 5.

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Box 19

Table 5
Results of thermal-structural study of brake discs

Analysis	Maximum value	Minimum value	Unit
Thermal	677.45	494.47	°C
Structural-thermal	1.0075	0.11194	mm
von-mises stress	6521.3	4.2042	Pa

Source: Own elaboration

The high temperature of 677 C° suggests that the brake disc is experiencing significant heating during operation. This temperature may contribute to thermal expansion of the disc, which in turn causes the maximum deformation of 1.0075 mm. It is important to assess whether this deformation is acceptable in terms of the design specifications and functionality of the brake system. From these results, the final numbers were compared with data from other universities, having the information shown in tables 6 and 7.

Box 20

Table 6
Comparison of physical properties of brake discs in SAE Formula projects

University	Material	Diameter (mm)	Thickness (mm)	Weight
UPAEP	Cast iron	200-200	4	1.487
ULL ESIT	6061 aluminium	202.66-157.64	15	1.15
University Carlos III	Graphite laminate	267-220	16.1	2.6
HTW Berlin	AISI 4142 steel	220-200	5	2.15
IPB	Aluminium alloy	205-150	4	N/A
IPN	Stainless steel	220-142	3	0.721

Source: Own elaboration

Box 21

Table 7
Comparison of brake disc load data in SAE Formula projects

University	Load capacity (N)
UPAEP	2336.11
ULL ESIT	3000
Carlos III University	4500
HTW Berlin	2700
IPB	5305.45
IPN	5409.5

Source: Own elaboration

Conclusions and future work

Even taking into account that the disc chosen has a load capacity very close to the minimum permitted, the objective is met according to the results of the analyses, the deformations suffered by the disc under normal working conditions are within the acceptable range for its use.

The development and optimisation of the braking system for the Formula SAE vehicle of the UPAEP University team has been a project of great relevance and technical challenge. The previously proposed braking system, although functional, presented significant limitations in terms of cost and efficiency, which motivated the search for a solution more suited to our specific needs.

In the course of this project, detailed calculations were carried out to determine the optimal specifications of the new brake discs. These calculations identified the critical parameters necessary for the design of a braking system that would not only meet the technical requirements of Formula SAE competition, but would also be economically viable. The research and analysis led to the selection of a national supplier, capable of supplying both brake discs and spare parts, thus ensuring greater sustainability and affordability in the maintenance of the system. The decision to implement the same type of brakes on all four wheels was strategic, seeking to improve both the performance and economy of the project.

This uniformity not only simplified the procurement and maintenance process, but also contributed to a better distribution of braking forces and greater vehicle stability in demanding conditions. In conclusion, the renovation of the braking system has not only met the technical and economic objectives set, but has also provided a solid basis for future developments and improvements in the performance of the Formula SAE team of the UPAEP University.

This project demonstrates the importance of a comprehensive and analytical approach to engineering, as well as the advantage of leveraging national suppliers to strengthen local industry and optimise available resources.

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Following the successful optimisation of the braking system for the UPAEP University team's Formula SAE vehicle, it is imperative to continue with the development and materialisation of this project in its entirety. The next phase must focus on the construction and physical implementation of the optimised braking system, in order to validate the theoretical calculations and technical specifications previously determined.

Successful implementation of the optimised braking system will open the door to further continuous improvement projects for the Formula SAE vehicle. Possible areas of development include innovations in materials and design, research into new materials and technologies that can offer additional advantages in terms of weight, durability and efficiency. As well as integration of electronic systems and development of electronic control systems that optimise braking performance in real time.

Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that could have influenced the article reported in this paper.

Authors' contribution

The contribution of each researcher in each of the points developed in this research was defined based on:

López-Flores, Jennifer-Guadalupe: I contributed in the analysis and selection of the brake disc, ensuring compliance with the theoretical analysis and its numerical validation.

Cordero-Guridi, José de Jesús: I contributed to the development of the method, the research method and the analysis of the thermal-structural evaluations.

Ovando-Cuevas, Enrique Romeo: Developed the thermal-structural studies and was in charge of their numerical validation.

Yescas-Ávila, Eber Alonso: Contributed to the analysis of the fundamental equations of the braking system and the study of the data from the universities with which the results were compared.

Acknowledgements

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Abbreviations

afv - Negative acceleration
CAD - Computer Aided Design
CG - centre of gravity
D - Disc Diameter
Fcfsf - Front Caliper Force With Safety Factor
Fcf - Front Caliper Force
Fcp - Front Caliper Pressure
Fcpr - Front Caliper Piston Radius
Fd - Front Axle Brake Force
Fdr - Front Brake Disc Radius
FEA - Finite Element Analysis
Ffmax - Brake force max
Ffd - Brake force front axle
Ftf - Friction torque at front corner
Fmcd - Front Master Cylinder Diameter
Fmcf - Front Master Cylinder force
g - Gravity
Hcg - Height centre of gravity
kPa - kilo Pascals
L - wheelbase
Lf - Front axle distance
Lr - Rear wheelbase
Nd - Braking torque front axle
Nt - Braking torque rear axle
Pd - Front axle weight
Pfd - Front braking torque
Pft - Rear braking torque,
PF - Fluid pressure
Rcp - Rear Caliper Pressure
Rcpr - Rear Piston Radius
Rcf - Rear Caliper Force
Rcfsf - Rear Caliper Force With Safety Factor
Rcfsf - Rear Caliper Force With Safety Factor
Rdr - Rear Brake Disc Radius
RED - Effective Disc Radius
Rnd - Effective Tyre Radius
Rmcf - Rear Master Cylinder Force
Rmcd - Rear Master Cylinder Diameter
Sf - Safety Factor
SPC - Surface of caliper piston
TP - Weight Transfer

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TF - Brake Torque
utf - Coefficient of friction rear tyre
utr - Coefficient of friction front tyre
W - weight
Wfb - Weight on front axle
Wfb aero - Weight at front axle with downforce
Wr - Rear weight percentage
Wrb - Rear axle weight
Wrb aero - Rear axle weight with downforce
Wrp - Rear axle weight percentage with downforce
Wrp - Percentage of rear weight
Wf - Percentage of front weight
Wfp - Front weight percentage
Wtf - Weight transfer

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Article

Evaluation of operational efficiency in a company dedicated to the manufacture and sale of coolers

Evaluación de la eficiencia operacional en una empresa dedicada a la fabricación y venta de coolers

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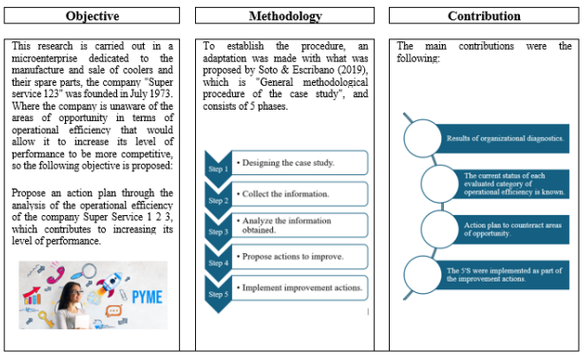
Abstract

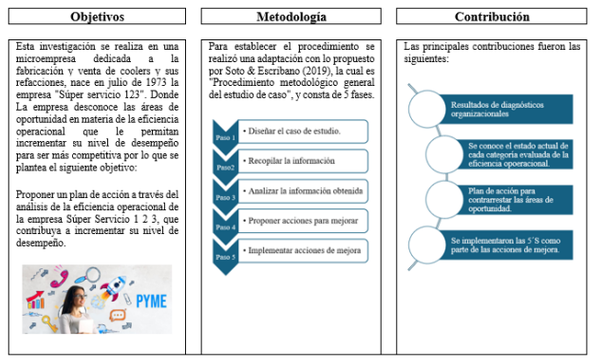
The study at Súper Servicio 123, dedicated to the sale and manufacture of coolers, identified the need to improve its operational efficiency. The objective was to propose an action plan based on the analysis of its efficiency to increase its performance. The procedure included five phases: study design, collection and analysis of information, proposal and implementation of improvements. A self-assessment was applied that showed an efficiency of 75%, while an audit revealed 45%, highlighting deficiencies in Marketing and Sales, Operations and Human Resources. The 5S methodology was implemented with the expectation of significantly improving efficiency. The objective of the project was met and it is recommended to use the instrument developed to evaluate efficiency after applying the 5S methodology and the recommended actions to improve organizational performance.



Operational efficiency, improvement and SMEs

Resumen

El estudio en Súper Servicio 123, dedicada a la venta y fabricación de coolers, identificó la necesidad de mejorar su eficiencia operacional. El objetivo fue proponer un plan de acción basado en el análisis de su eficiencia para incrementar su desempeño. El procedimiento incluyó cinco fases: diseño del estudio, recopilación y análisis de información, propuesta e implementación de mejoras. Se aplicó una autoevaluación que mostró una eficiencia del 75%, mientras que una auditoría reveló un 45%, destacando deficiencias en Mercado y Ventas, Operaciones y Recursos Humanos. Se implementó la metodología 5S con la expectativa de mejorar significativamente la eficiencia. El objetivo del proyecto se cumplió y se recomienda usar el instrumento desarrollado para evaluar la eficiencia tras aplicar la metodología 5S y las acciones recomendadas para mejorar el desempeño organizacional.



Eficiencia operacional, Mejora y Pymes

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Introduction

Entrepreneurship in society has caused the creation of MSMEs (small and medium-sized businesses) around the world, which has been considered a positive strategy for the development and socioeconomic stability of the regions where they are located, because it allows for the creation of jobs, reduce poverty rates, and are characterized by their innovative dynamism and their ability to adapt to constant changes in their environment. Currently, approximately 99% of companies globally are SMEs and employ 50% of the workforce. and contribute 50% of GDP worldwide (Baltodano & Leyva, 2020).

Talking about entrepreneurship means taking into account the contributions that a community makes as a factor that is determining for economic, social and structural development but it is also seen as a driving force that stimulates the acquisition of knowledge, technological change, competitiveness and innovation (Herruzo et al, 2019).

Small family businesses constitute one of the most important inputs for economic development. Today there are still many difficulties in quantifying the role of entrepreneurship and small and medium-sized businesses and their location within other links related to economic development. The new trends of the fourth industrial revolution have created new opportunities for this type of business, including new technologies, new ways of conducting operations and access to more data. In addition to that, it has also introduced new risks such as cybersecurity among others (Pavlova, 2021).

In this sense, through a study by Ngele & Nzelibe, (2023), they consider that business skills are a crucial part in the development of this type of business since it allows commercial operations to be executed in the best way, with Quality and effortless therefore require small and medium business entrepreneurs to adapt to these new current trends.

Some of the reasons why MSMEs do not achieve considerable development is because they are very similar to each other even though they are from different lines and sectors with low professionalization in their operations because they begin their operations informally, which causes them to commit mistakes frequently and even close their doors. It is also important to consider what were the reasons that led the entrepreneur to start the business, whether it is because he only considered it as an opportunity or because of some need to earn income, since the efforts made by the entrepreneur to develop the business depend on this. And adding to it the lack of management in its operations by the owners and the rest of the collaborators, there will come a time when growth stagnates because they do not have the necessary tools to direct it (Vázquez, Tamez, Recio & Gómez, 2021).

For Chase & Jacobs, (2022), efficient operational management refers to the ability of an organization to obtain high performance by minimizing the use of its resources. To be competitive, companies must achieve operational efficiency, which is achieved when they manage to reduce their costs to their lower limit and raise the quality of the products or services delivered to their customers to the maximum upper limit and at the same time add value. which allows for greater consumer satisfaction.

Some research in operational management addresses, depending on the nature of the business sector, the following categories of analysis; (a) development of contingency plans for accidents or spills, (b) establishment of controls, (c) establish management indicators, (d) manage monitoring, (g) implement preventive maintenance plans, (h) carry out maintenance programs personnel integration, (i) implement training plans and programs, among others (Vásquez et al., 2019).

The technical efficiency of companies in Mexico according to the Organización Internacional del Trabajo (2021), the economy has achieved macroeconomic stability and outstanding performance of the export sector. However, stagnation in productivity has hindered growth in the economic sector and the generation of quality jobs.

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To evaluate productivity, it is very useful to consider the level at which the technical efficiency of companies is carried out, since current production is compared to an optimum. Most of the studies carried out on current events in Mexico focus on productivity growth over time and analyzes of technical efficiency.

The operational efficiency that addresses business problems day by day is not sustainable in the long term since it only covers the short term to achieve operability. The strategy requires this operation to be implemented, then success would lie in achieving the balance between what encompasses operational effectiveness and the business strategy so that development and competitiveness can be achieved (Salinas, 2019).

For (Cruelles, 2019) points out a difference with respect to business strategy and operational efficiency, it is mentioned that for Michael Porter the first is related to achieving the objectives established by the organization, while the second is reflected by the use of resources to achieve objectives, always trying to obtain the best possible results at the minimum cost.

Currently, SMEs face an environment of constant change, globalization of capital markets and goods and services, and a growing importance of costs and productivity to be competitive. To remain in these increasingly larger, dynamic and demanding markets, they must develop all their adaptation and anticipation capabilities. It is essential to consider that many of the economic objectives that are sought to be achieved in the short term depend on several factors, including specialized and trained labor. This work aims to demonstrate that in Mexico there is a lot of untapped talent. Furthermore, another factor that slows the growth of SMEs is financial, since many of them struggle to obtain the necessary resources to be productive and survive, which will also be analyzed in this study (López, 2018).

A study carried out by Real et al (2020), applied to 319 companies distributed in the municipalities of Caborca, Cajeme, Hermosillo, Navojoa and Nogales in the State of Sonora, where 50.5% are established companies, 26.6% are newly created and 19.1% are recently created companies, in addition 40.8% have higher education, 20.1% upper secondary education and 17.6% higher technical education, there they found in their evaluation of the part of the social impressions of the entrepreneurial environment in Sonora that 93.7% do consider that starting a business is a good career option, which is why they considered it positive and encouraging for all those people who want to start a business. Within the evaluation of the attitudes and perceptions of entrepreneurs, they found that 77.4 % perceive good opportunities to start a business, 87.1% have sufficient skills to start a business, so they considered a positive attitude on the part of entrepreneurs to start a business. Considering these results and also the causes why SMEs do not achieve their development, it can be concluded that the conditions for this type of business are favorable in Sonora and with a series of strategies aimed at minimizing these causes could enhance their efficiency, productivity and development.

This research is carried out in a micro-business dedicated to the manufacture and sale of coolers and their spare parts. The company "Súper Servicio 123" was born in July 1973. The father of the current owners of what is now the business under study - and who would later become the sole owner of the business - started the Camacho furniture store in partnership with one of his brothers in the current location of 1 2 3 Súper Servicio (Puebla Street 401-OTE, Centro, Cajeme). At that time, the business's product line was only colonial-style furniture (Super Servicio 1 2 3, 2023).

The boom of the business took place between 1982 and 1990. The public's demand for products exceeded the capacity of the business. During this period, the owner's children began to attend the premises in the afternoons. Since 1990, the children of the then owner and current owners would remain in charge. At that time, the strength of the business was manufacturing and repair. Around the year 2000 1 2 3 Super Servicio would diversify its products a little more, adding washing machines and refrigerators to its lines (Super Servicio 1 2 3, 2023).

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In 2010, the company set out to integrate air conditioners into its product lines, specifically those of the Mirage brand. Due to various factors, such as: the fact that the public knew 1 2 3 Súper Servicio as a reference in coolers and not in air conditioning, the requirements demanded by suppliers, the existence of a strong competitor with a long history in air conditioning and its ability to offer them at low prices, etc. They forced the company to abandon the air conditioning line (Super Servicio 1 2 3, 2023).

Today, the strength of the business is more than anything the purchase and sale of spare parts and new equipment, predominantly aerocoolers - the latest in technology regarding coolers, which the owners believe will end up displacing the classic cooler. Currently, the business's sales concern 70% of the air cooler and 30% of the cooler (Super Servicio 1 2 3, 2023).

In an-interview with the business administrator, the operation of the business was investigated in the following seven sections: (1) Products, (2) Suppliers, (3) Customers, (4) Control of information and/or processes, (5) Facilities, (6) Software, (7) Human relations.

Regarding the product category, the items handled in the company cover a wide variety of products which are: turbines, hose bands, etc. Each of them has a different classification, for example: Washing machine spare parts, refrigerators, cooler spare parts and air coolers. There are products that deteriorate over time because they are no longer used or have become obsolete (Super Servicio 1 2 3, 2023).

On the other hand, regarding the suppliers that the business under study currently has, most of them are internal suppliers, there are also 10 foreign suppliers, they are constant in their delivery and have a very close relationship with them, some of the requirements required on their part are the punctuality and quality of the products (Super Servicio 1 2 3, 2023).

The company also has a wide variety of clients, the service it offers is the purchase and sale of spare parts and from the administrator's perspective, in relation to the service, it is sought to carry them out with punctuality, efficiency, and effectiveness as a priority. 70% of sales are to the general public and the other 30% are local companies (Super Servicio 1 2 3, 2023).

It was identified that the company has a management style based mainly on the experience of the commercial line, but the administrative practices they carry out present many areas of opportunity, including the lack of indicators, management, adequate inventory control, information control manual, there is no marketing strategy or sales campaigns, etc. (Super Service 1 2 3, 2023).

There are fire extinguishers and security in case of fires, however it was identified that they are not correctly placed, half are only installed while the other half are on the ground and difficult to access due to the accumulation of objects (Super Service 1 2 3, 2023).

In the software section, the Excel and Word system is used only, they handle the billing and sales that exist per day, errors have occurred in data capture due to the obsolete computer that the company has (Super Service 1 2 3, 2023).

Finally, the human relations section is functionally dependent on its suppliers and has a quality system role which is that the merchandise sent comes without errors and there are no defects (Super Servicio 1 2 3, 2023).

In an initial tour of the company's facilities, a lack of order and cleanliness could be perceived, due to the fact that over a long period of time no actions have been taken to organize and clean the spaces and as a result there is an accumulation of objects that They may be obsolete or not necessary for the operation of the business, reflecting waste and high search times.

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At Super Servicio 1 2 3, it currently lacks efficiency in its operations, this is reflected in a lack of control in the product warehouse due to poor organization and delays in the warehouse coupled with a lack of cleanliness in the facilities, the use has not been made of technology as support for internal management and the purchase and sale of products and services, there is no purchasing plan aligned to the levels of demand per season....due to all of the above, the following approach to the problem is established:

"The company Super Servicio 1 2 3 is unaware of the areas of opportunity in terms of operational efficiency that allow it to increase its level of performance to be more competitive".

Objective

Propose an action plan through the analysis of the operational efficiency of the company Super Servicio 1 2 3, which contributes to increasing its level of performance.

Method

Object

The object under study of this research project is the operations carried out by the company Super Servicio 1 2 3, to achieve its commercial strategy, including all the key areas involved in the operation, including leadership, sales, warehouse purchases, production, customer service. to clients, human resources, etc.

Materials

The materials that were used to carry out the research for this project are mentioned below:

- JICA methodology proposed by (Pineda, 2013)
- Methodology proposed by Soto & Escribano, 2019), five phases are included, which will be seen in the following section.
- National model for organizational transformation.

Procedure: To establish the procedure, an adaptation was made with what was proposed by Soto & Escribano (2019), which is "General methodological procedure of the case study", it consists of 5 phases, each of which is described below.

1. Design the case study: Depending on the problem addressed and the objective pursued by this research, the variables to be addressed were identified, an investigation was carried out to know the methodologies that can help us improve operational efficiency, subsequently an analysis was carried out on the areas that includes operational efficiency from the perspective of other researchers, derived from this analysis the areas to be considered for the evaluation of operational efficiency were obtained, the result is shown in a table which shows areas and sub-areas.

2. Collect information: To measure operational performance, the structured interview technique was used to explore the operational efficiency of the company under study, as well as a checklist to evaluate the level of performance of the company from the perspective of its administrator. The areas considered to study operational efficiency were those considered by the JICA method proposed by Pineda, (2013), among which Marketing and Sales, Operations, Human Resources, Finance and Administration stand out.

The study subjects considered for this research were the business administrator and his collaborators, the interview was conducted directly with the business administrator and the survey was applied to both the administrator and the employees. To collect information, the scale shown in Table 1 was used, under which each of the questions was evaluated. Below is Table 3 which shows the evaluation in 5 levels.

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Box 1

Table 1

Evaluation in 5 levels

QUALIFICATION	INDICATOR (The activity or function)
5 Excellent	➢ Yes, it is fully known and applied to a high degree.. ➢ Always formal and documented in writing. ➢ It is constantly updated. ➢ All staff know it. ➢ It is fully consolidated. ➢ It is counted on. ➢ Completely efficient.
4 Good	➢ It is formally written, it is not updated. ➢ It is almost always used, but not entirely. ➢ It is about to be consolidated.
3 Regular	➢ It is carried out informally. ➢ Yes, but it is not put into practice very frequently. ➢ Sometimes it is efficient.
2 Bad	➢ It is rarely done. ➢ It is partially documented. ➢ It is almost unknown by the staff. ➢ Almost zero results. ➢ It is carried out or documented in an obsolete manner.
1 Very bad	➢ Not done. ➢ Does not exist. ➢ Everyone is unaware of it. ➢ They don't even know they have to do it.
Not Applicable 0	Note: When a question has no way to be evaluated, it is canceled and will not count toward the feasibility score.

Source: Own elaboration.

To collect the information, a stay was carried out within the company with a duration of 4 months in which the previous instruments were applied where direct observation could be applied by visualizing the activities of the leaders and the set of values and habits carried out to obtain a judgment of the performance in the different categories of analysis of the instruments used.

3. Analyze the information obtained: The analysis of the collected information was carried out once the survey information was captured in Excel, the averages were obtained by item rating and subsequently an average of the items by areas of the model was obtained, to subsequently obtain a global rating item of the business operational efficiency. Subsequently, a report was made on the current state of business performance in relation to the variables used in the data collection instruments based on the model established in this research.

4. Propose actions to improve Operational Efficiency: Derived from the analysis of the information obtained after having applied the diagnosis to the company, an action plan was generated which is presented as a list of improvement actions for the company under study, considering general actions that support improving the categories that presented considerable areas of opportunity.

5. Implement improvement actions: Later in this step, the implementation of a 5s program was carried out as the first action to improve operational efficiency, with the intention of impacting waste management, inventories and the service provision process, the phases carried out for this program were; select, organize, clean, standardize and discipline.

Results

Below are the results obtained from each of the steps established in the method, necessary to achieve the objective of this research.

1. Design the case study.

The problem of this research that was previously established through the following approach "The company Súper Servicio 1 2 3 is unaware of the areas of opportunity in terms of operational efficiency that allow it to increase its level of performance to be more competitive", derived from This approach distinguishes the following variable:

Number of opportunity areas: represented by all areas in which the evaluation of the level of performance has been low based on the established evaluation scale.

Based on the above, the objective derived from the results of this project is to "Propose an action plan through the analysis of the operational efficiency of the company Súper Servicio 1 2 3, which contributes to increasing its level of performance." In the next phase, an analysis of the areas that include operational efficiency is developed from the perspective of several researchers (See table 2).

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Box 2

Table 2

Analysis of operational efficiency models

Model	Turn	Areas of operational efficiency considered
Espinoza, Garagundo, Lecca, Orrillo, & Tito, (2018)	Distribution	• Maintenance • Fuel consumption • Operational safety • Care of the Environment • Cost management • Staff training
5'S	Store	• Service • Operations • Shopping • Facilities • Inventories • Operational indicators • Costs and waste
National competitiveness model	SMEs and productive organizations	• Strategic direction • Leadership • Customer orientation • Digital transformation • Human capital • Social value • Processes for generating value
100 technological improvements	SMEs	• Administration • Human Resources • Finance • Quality • Processes and products • Energy savings • Environmental aspects
Modernize yourself	Tourism	• Management system • Processes • Human development • Information and diagnosis system • Company management • Administration and finances • Marketing
JICA Methodology	SMEs	• Administration • Operations • Marketing and sales • Human resources • Finance

Note: From the information provided from the different models, the list of dimensions to be considered as a model for this research was generated.

Source: Own elaboration

Of the methods presented in table 2, the JICA methodology proposed by Pineda, (2013) was chosen because it presents areas and sub-areas that are directly related to the way of operating of the company under study, see in the table 3 the areas considered.

Box 3

Table 3

Areas considered for operational efficiency

Categories	Areas of operational efficiency
Administration	• Top person responsible for business administration • Social responsibility • Management strategies • Administrative organization • Information • Management plans
Operations	• Quality • Costs • Processes • Methods Equipment and facilities • Materials, purchases and suppliers • Inventory • Operation administration
Marketing and sales	• Marketing • Strategy • Customer satisfaction • Sales activities • Service for products • Marketing
Human resources	• Admission and employment • Evaluation systems • Communication • Capacity development • Wellbeing and safety • Human resources policy
Sales	• Financing • Investment plan in facilities and machines • Profitability • Security (financial structure) • Capital liquidity • Procedures and accounting systems

Note: Based on these dimensions, a self-assessment and an evaluation in the form of an audit will be carried out to evaluate from the researcher's perspective

Source: Own elaboration

3. Collection of information

To collect the information, a structured interview was carried out with the company's administrator with the purpose of detecting areas of opportunity. Additionally, a checklist was used, which was implemented in two modalities, one of which is a self-assessment by the same administrator. and their collaborators, and another in the form of an audit that managed the dimensions established in the previous step.

3. Analyze the information obtained

Once the information was collected, the data was captured in Excel, obtaining the averages by rating of the items and by areas of the model, subsequently the overall rating of the operational efficiency of the business was obtained. With the data obtained, a report was made on the current status of the company under study.

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The results obtained with this evaluation showed a score of 75% operational efficiency, from the perspective of the businessmen in the self-assessment carried out, while in the evaluation carried out by the research body through an audit an operational efficiency of 44% was obtained, The information is detailed below with an analysis by dimension and by subcategories.

Dimensional analysis

Below, you can see the results graphically which show the levels obtained in each of the dimensions evaluated. In the following graph (Figure 1), you can see the results of the five dimensions evaluated in their entirety, which are: human resources, marketing and sales, operation, administration and finally finances, it is important to mention that the results were considered generated by the self-assessment and those of the audit carried out.

Box 4

Figure 1
5 Dimensions Chart

Source: Own elaboration.

Note: As can be seen in the figure, the dimensions that have the best rating when evaluated by both the audit and the self-assessment are finance and administration, which are the most notable compared to the other 3 dimensions, where you can find many areas of opportunities for a better organization, Operation is the dimension with the lowest score due to its traditional work method, without much use of technologies.

Subcategory análisis

Figure 2 is shown below, which shows the results of the Administration dimension, taking into account the evaluation by the businessmen and the audit by the body of work, finding areas of opportunity in this graph.

Box 5

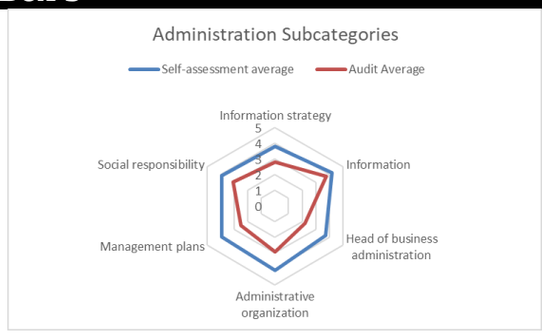

Figure 2
Graphics of the subcategory of the Administration dimension

Source: Own elaboration.

Note: In the Administration subcategory, a great difference can be seen in the management of information since they have their records in order on a weekly basis where each of the managers are aware of the internal information that is handled.

Other high-scoring points are the Social responsibility and the administrative organization where effective communication by the administration stands out, ensuring constant knowledge of the current situation of the company and devising strategies for better internal functioning, where a lack of attention can be clearly seen in the Management plans and its maximum manager since they do not have a clear knowledge of all its advantages and disadvantages, where in recent years there has not been a clear improvement in sales and its administrative development, having a clear lack of strategic plans for the medium and long term.

Below, shown in Figure 3, some performance graphs are shown per item in the Administration dimension, with a notable difference in each of the items with respect to the evaluation and audit carried out.

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Box 6

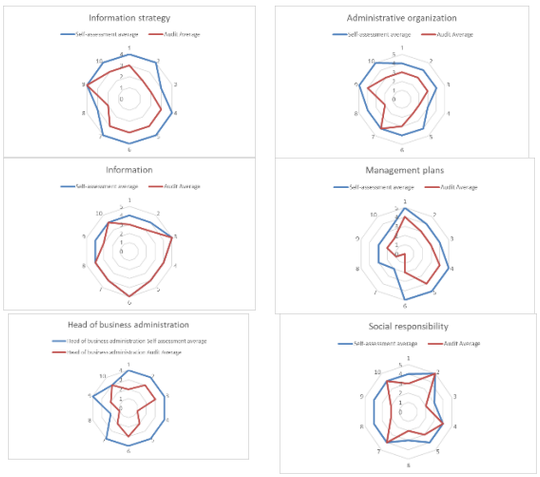

Figure 3
Graphs corresponding to the performance by item in the subcategories of the Administration dimension
Source: Own elaboration

Note: This figure shows the 6 subcategories and the respective score for each question asked in the evaluation where the aim was to locate the weakest and strongest areas, thus in the administration category where there is an irregularity in each of the subcategories comparing the self-assessment. and the audit in it, where few points coincide with both graphs. In the following figure 4, you can see the graph of the Operation dimension, where it showed weak results for the company and thus the detection of opportunities for improvement in the following points: Operations management, Development and process control, Team control and facilities, inventory control and process control.

Box 7

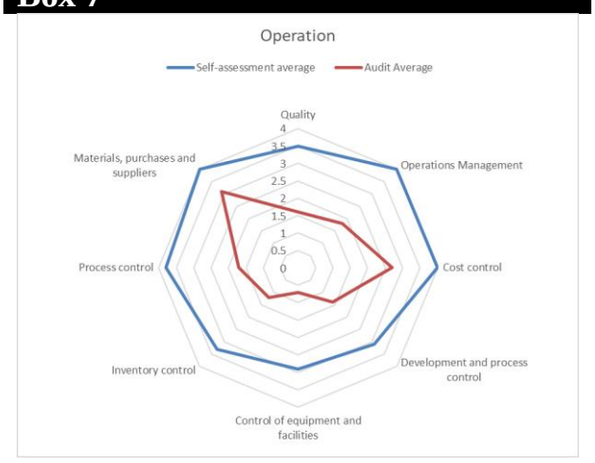

Figure 4
Graphics of the subcategories of the Operations dimension.
Source: Own elaboration.

Note: The previous image shows the different subcategories in the operations dimension which show a low percentage in the following areas: Operations Management, Development and Process Control, Equipment and Facilities Control, Inventory Control and Process Control.
The following figure 5 shows the graphs that correspond to the performance per item of the operations dimension, which can be seen to have five weak items for the company and thus be able to provide solutions to each of them.

Box 8

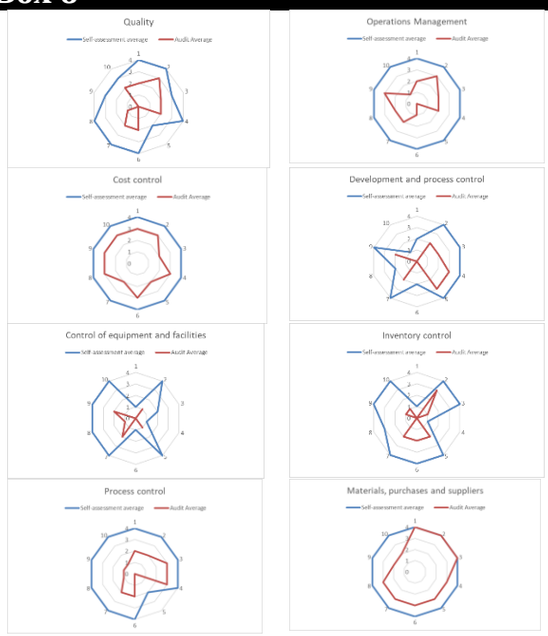

Figure 5
Graphs corresponding to the performance by item in the subcategories of the Operations dimension.
Source: Own elaboration.

Note: In the subcategories of the operations dimension, the difference between the self-assessment and the audit is clearer, where five items can be observed below the level expected by the company.

Next, figure 6 shows the Marketing and Sales dimension in which two opportunities for improvement were found, the weak categories of this dimension being strategy and marketing and sales; improvement actions were carried out in these. two items.

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Box 9

Figure 6
Graphs of the subcategories of the Marketing and Sales dimension

Source: Own elaboration

Note: In this marketing and sales category, you can clearly observe its two strengths, which are the service and the satisfaction of its clients due to good quality work, where they are denoted and therefore there is greater opportunity for improvement in the sales strategies and the marketing, where there is a lack of future plans and little information acquired about technological innovations.

You can see in figure 7 the graphs corresponding to the performance by item in the Marketing and sales dimension, where the difference in the strategy and marketing and sales item with respect to the others can be seen.

Box 10

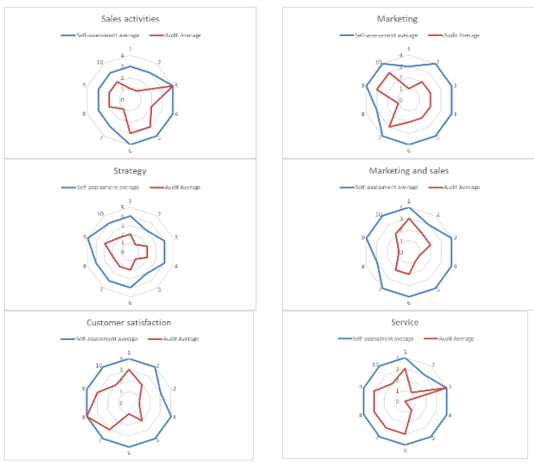

Figure 7
Graphs corresponding to the performance by item in the subcategories of the Marketing and Sales dimension.

Source: Own elaboration

Note: Likewise, you can see in this figure the differences when evaluating in each of the subcategories where the two parties only agree on a few points and the audit being an evaluation with a lower score with respect to the self-evaluation of the same company.

Below, figure 8 is shown, the Human Resources dimension, which highlights four weak points in this category which were: Admission and employment, Well-being and security, Human resources and finally Evaluation system.

Box 11

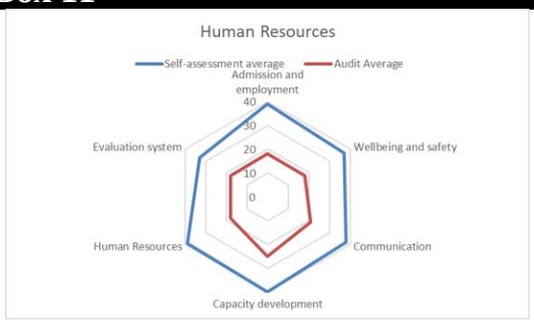

Figure 8
Graphs of the subcategories of the Human Resources dimension

Source: Own elaboration

Note: In the subcategories of the Human Resources dimension, the high score in Capacity Development stands out compared to the other subcategories, where the correct and quick training of employees is sought so that a good job is done, another strong point. In this section it is the Communication section where the effectiveness within the company stands out, keeping the partners informed of the company's situation, as can be seen one of the points where it has the most problems is in the evaluation system, where They do not have a method to evaluate candidates to occupy a position in the company, they simply seek to train applicants in a good way and thus hire them.

Figure 9 is shown below, which shows the graphs that correspond to the performance by item of the human resources dimension in which a clear difference is noted with respect to the self-assessment and the audit, where 4 weak items were found by the company.

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Box 12

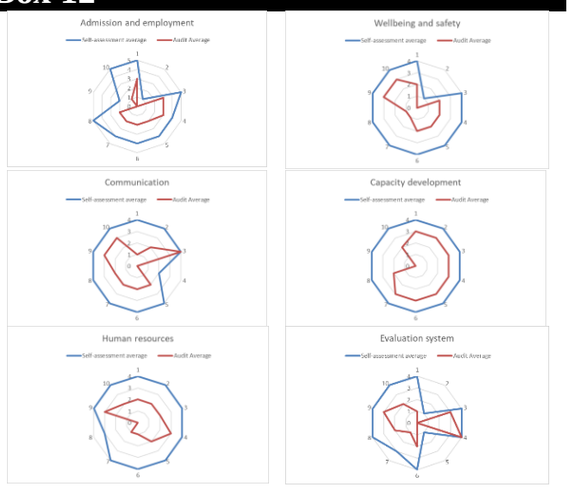

Figure 9
Graphs corresponding to the performance by item in the subcategories of the Human Resources dimension.
Source: Own elaboration.

Note: This figure shows the deficiencies in the subcategories of the HR dimension, which were admission and employment, well-being and security, human resources and evaluation system, where likewise the audit and the company's self-evaluation have a discrepancy. at the time of evaluation regarding the score for each of the questions.

Figure 10 is shown below, which shows us the graphs of the finance dimension in which a greater coincidence is observed with respect to the evaluation and audit carried out in each of the subcategories.

Box 13

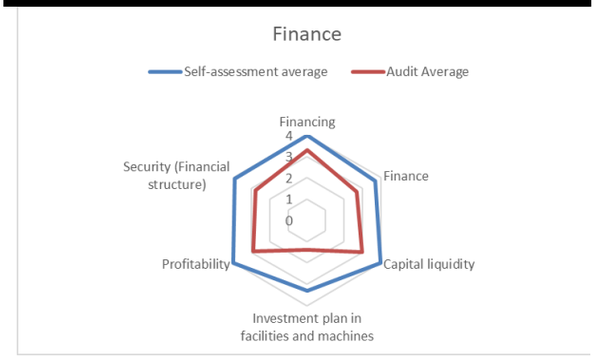

Figure 10
Graphs of the subcategories of the Finance dimension.

Source: Own elaboration

Note: In the finance dimension there are 6 subcategories where the majority stands out for their good score acquired in the evaluation, except in the investment plans, where due to lack of information and knowledge of technology.

The following figure 11 shows the performance by item of the finance dimension, which there is little difference with respect to the self-assessment and audit that was carried out in the evaluation, there is a greater coincidence in each of them, therefore no areas were detected. of opportunity.

Box 14

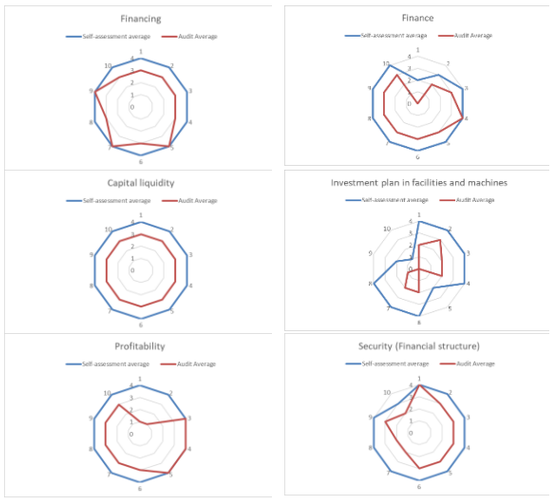

Figure 11
Graphs corresponding to the performance by item in the subcategories of the Finance dimension.
Source: Own elaboration

Note: In the figure showing the Finance subcategories, with respect to the other dimensions, it can be seen that self-assessment and audit have greater coincidence when evaluating each point of the subcategories.

4. Propose actions to improve Operational Efficiency.

In accordance with the general results obtained in the evaluation of operational efficiency which is taken as a reference to make proposals for improvement, the results obtained in the audit carried out by the research team, this is because it reflects to a greater extent the reality of the company from an objective point of view according to the evidence shown.

The areas that presented the lowest levels of operational efficiency are those of. Operations, Human Resources and Marketing and Sales, therefore, the recommended actions focus on improving efficiency specifically in the subcategories that presented one lower level, which are presented below in table 4.

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Box 15

Table 4

Proposals to improve Operational Efficiency

Categories	Improvement actions	Purpose
Operations		
Operations Management	Process map	Have the company's processes identified and relate some processes to others according to their order of execution.
Development and process control	Process documentation	A process documentation is a detailed description of how to carry out a process, it describes the exact steps needed to perform a task..
Control of equipment and facilities	Implementation of a quality management system	Implementing a quality management system will help maintain the effectiveness of operations, keep customers satisfied.
Inventory control	Permanent 5'S program.	Having a permanent 5'S program aims to ensure that the company is clean and orderly at all times to increase productivity, improve work areas and increase the personal efficiency of the work team..
Marketing and Sales		
Strategy	Develop a strategic sales and marketing program	Developing a market analysis will allow you to know information about how many competitors exist in the area being developed, predict the changes in terms of the products involved and whether the public would be willing to buy it and what would be the price that would be paid for it..
Marketing and sales	Develop a market analysis	Having a strategic program will serve to identify where the organization wants to go and what actions will be taken to achieve the objective..
Human Resources		
Admission and employment	Establish a safety and hygiene program.	A safety and hygiene program is a plan that allows you to eliminate risks that threaten the safety and health of workers..
Wellbeing and safety	Establish personnel selection and hiring processes.	A personnel selection process will help to better know the candidates to obtain the job, who is the most suitable to perform in the position.
Human Resources	Establish job profiles	Establishing a job profile is necessary in a company, it helps measure the performance of each worker..
Evaluation system	Establish a performance evaluation system	With the purpose of establishing a performance evaluation system in an organization, it is very important since it has to determine the value of the work that was performed by a worker in a company, it measures the level of competitiveness of the organization, it measures the performance of workers, encourages communication and identifies strengths and weaknesses.

Source: Own elaboration.

Note: The improvement actions are presented to the company under study where it is indicated which tool is proposed to be used to increase operational efficiency in the organization, the purposes of the improvement action are also mentioned where it justifies and helps understand why they are taken. into account.

5. Implement improvement actions.

It was decided to implement the 5'S methodology because it brings great benefits to all the areas that were considered in the evaluation instrument, since it broadly encompasses significant improvements such as reduction in search time for sales items, a good organization and cleanliness of selected areas, improves employee habits, inventory controls.

As a first action, a talk was held with the business owners as initial training in which the content of the 5S program was discussed. A diagnosis of the initial situation of the company was also carried out in relation to the main axes of the 5S philosophy, in which results of only 50% compliance with the program requirements were obtained.

The main areas of non-compliance were the following: There is accumulated material in the work areas, the work areas are not tidy, the work area is considered not clean and there are items in the area that do not belong to it. and it is not known who they belong to.

In the selection stage, all items that should be rearranged because they were poorly located, because they were obsolete, because they did not work, or because they were disorganized, were identified through a red card campaign with a label.

Subsequently, in the sorting phase with the labeled articles, most of them were discarded, with the rest of the articles their order was decided based on the following criteria: Areas were established to place the articles by families and by frequency of mobility in the store.

At the beginning of the project, each of the areas had a lot of dirt, which is why the fourth cleaning action was carried out, a cleaning campaign was carried out, the sale items were mostly very dusty. which proceeded to carry out a deep cleaning in the following areas of Warehouse A and B, Counter and Workshop. As a strategy to increase the effectiveness in carrying out cleaning, a cleaning log was carried out on a permanent basis so that in each area that the company has, there is someone responsible and is in charge of carrying out the tasks. corresponding activities that are periodically scheduled for execution.

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In the standardization stage, visual signs were established on all the shelves that the company counts, generating codes with Roman numerals to label each shelf that the company counts followed by a letter that identifies the column of the shelf (When it has two or more columns), finally a number that identifies the row of the shelf, this with the objective of being able to reduce the times in the delivery of products, we proceeded to place Roman numerals on the shelves that the company has to be able to identify them more quickly.

Finally, in the discipline stage to achieve a habit in the workers, it is suggested to implement 5'S patrols which consist of forming teams of collaborators who visit the different areas and carry out quick inspections and observations of non-compliance or well congratulations in case the 5'S are maintained. Another recommended action is to carry out the 5 minutes 5'S, which consists of at the beginning of the workday each area manager allocating 5 minutes to organize what is disordered at the time, likewise they could also allocate 5 minutes to the end of the work day ensuring that common use areas are also kept clean and tidy.

With these steps, it is expected that operational efficiency will be significantly improved in the different areas where greater areas of opportunity were presented during the evaluation carried out by the research team.

Conclusions

It can be concluded that the objective of this project was met, an action plan was proposed through an analysis, which contributes to increasing the performance level of the company. The importance of measuring operational efficiency is important in an organization, since it guarantees and makes it known that it is not spending too much on its processes and resources, it is more feasible for it to achieve its objectives and goals.

Based on the diagnosis of operational efficiency carried out from the perspective of the businessman, he self-assessed himself with a result of 75%, on the other hand, the same analysis was carried out through an audit where evidence was requested to evaluate the diagnosis by the research body, from which a result of 44% operational efficiency was obtained. The areas that were lowest were:

Marketing and Sales, Operations and Human Resources, in each of them improvement actions are recommended which try to increase performance in each of the organization's operations.

Although only one of the proposed strategies was implemented, it had several impacts in the areas where the project was carried out, such as: a significant reduction in the search for materials and sales items, a better image for customer service, an area cleaner and safer, accident-free, increased storage space, savings in inventory costs.

It is recommended by the research body to apply the instrument carried out in this project to know the level of operational efficiency obtained after implementing the recommended actions to increase the performance of the organization.

Author contribution

Israel Noriega Olivas: Contributed to the development of the method to achieve the results and documentation of the project.

Manuel Antonio González Mendivil: Contributed to the bibliographic and format review.

René Daniel Fornés Rivera: Contributed to the structure of the method and alignment of results obtained.

Adolfo Cano Carrasco: He contributed with the idea of the project, the method and the research technique.

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Article

Statistical analysis of the proportion of recycled edible oil in the quality of scented candles

Análisis estadístico de la proporción de aceite comestible reciclado en la calidad de velas aromáticas

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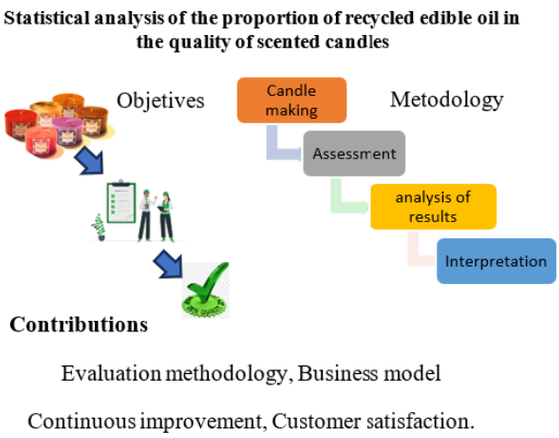
Abstract

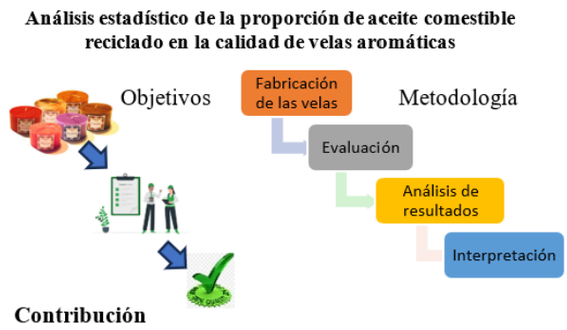
This work aims to analyze whether the variation in the proportion of recycled oil to make scented candles affects their quality. Three batches of candles were made at ratios 60-40, 70-30, and 80-20% of recycled oil and soy wax, respectively. The evaluation consisted of 7 tests: visual inspection, burning times, candle puddle, flame height, sensory rating scale, combustion afterglow check, combustion smoke, and post-combustion. The statistical analysis was performed using the MANOVA model. The multivariate test indicates a significant difference between the results of the quality tests of each batch of candles and the proportion used to manufacture the candles. However, the proportion of oil does not affect physical qualities such as color intensity, texture, imperfections, and aroma intensity.



Aromatic candles, Statistical, Multivariate, Quality Test, Recycling, Sustainability

Resumen

El propósito de este trabajo es analizar si la variación en la proporción del aceite reciclado para elaborar velas aromáticas afecta la calidad de estas. Se fabricaron 3 lotes de velas en proporciones 60-40, 70-30 y 80-20 de aceite reciclado y cera de soya respectivamente. La evaluación consistió en 7 pruebas: inspección visual, tiempos de combustión, charca de la vela. altura de la llama, escala de calificación sensorial, comprobación de posluminicencia de combustión, humo de combustión y poscombustión. El análisis estadístico se realizó empleando el modelo MANOVA, La prueba multivariante, indica que existe diferencia significativa entre los resultados de las pruebas de calidad de cada lote de vela y la proporción empleada para la fabricación de las velas, Sin embargo, la proporción de aceite no afecta las cualidades físicas como es la intensidad del color, textura, imperfecciones, e intensidad del aroma.



Velas aromáticas, Estadística, Multivariado, Pruebas de calidad, Reciclado, Sustentabilidad

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Introduction

Vegetable oil is an advantageous product not only in homes but also in restaurants and fast-food businesses, where it is used to prepare fried foods that are widely accepted due to their flavor and easy preparation. Frying is a complex physicochemical process where the food to be fried is subjected to high temperatures not exceeding 180 °C. The frying process modifies the surface and waterproofing of food to control the loss of water from its interior, improving, in most cases, the flavor, appearance, texture, and color (Valenzuela, Sanhueza, Nieto, Petersen, & Tavella, 2003). Overheating the oil produces toxic substances for consumption. In addition, it is a problem for the environment because it contaminates the water by capturing the oxygen that aquatic organisms need to survive and preventing sunlight penetration (Sanaguano-Salguero, Bayas-Morejon, & Cabrera-Carranza, 2019). It is known that one liter of oil can contaminate up to 40 thousand liters of water (González-Canal & González-Ubierna, 2015). According to the Federal Consumer Protection Agency, Mexico's per capita oil consumption in 2019 was 10 liters yearly (Ceballos-Bernal, 2021).

Currently, strategies have been developed that lead to the use of oil, such as the production of biodiesel, candles, and soaps, among other derived products (Aquino-Rivera, Ramirez-Ramirez, Soriano-Cabanillas, & Chang-Yong, 2021; Chivilchez-Palomares, Mendoza-Panihuara, Muñiz-Espinoza, Najarro-Pastor, & Villena-Lopez, 2019). Recycling these oils is of great help because it reduces the impact on the environment, promotes the proper management of these resources, and raises environmental awareness among citizens by observing that the quality of the products generated with this product does not compromise the quality of the same (Bravo-Bonete, 2023).

This work aims to analyze whether the variation in the proportion of recycled oil affects the quality of scented candles. The results obtained will be used to select the mixture that meets the characteristics similar to the scented candles on the market.

Therefore, three batches of candles were manufactured to achieve the objective, mixing 60-40, 70-30, and 80-20% of recycled oil and soy wax, respectively. The evaluation consisted of seven tests: Visual inspection, Combustion times, Candle puddle, Flame height, Sensory rating scale, Combustion afterglow check, Combustion smoke, and afterburning. Statistical analysis was performed using the MANOVA model. This multivariate technique indicated significant differences between the results of the quality tests of each batch of candles and the proportion used to manufacture the candles. However, the proportion of oil does not affect physical qualities such as color intensity, texture, imperfections, and aroma intensity.

Methodology

A quantitative investigation was carried out to determine the variation that exists in the quality of scented candles by varying the proportion of recycled oil in their composition and to determine what is the proportion of recycled edible oil that does not alter the quality of the manufactured candles and soy wax in the manufacture of scented candles. For the analysis of the results, the MANOVA statistical model was used. This analysis helped in the decision-making to determine whether the variation in the concentration of recycled oil affects the quality of the manufactured candles, thus raising two hypotheses:

H_0: The proportion of oil used in the manufacture of candles does not significantly affect the quality of scented candles.

H_1: The proportion of oil used in the manufacture of candles significantly affects the quality of scented candles.

Rejecting the null hypothesis indicates that there are significant differences in at least one of the quality tests between batches. The procedure of the research work is shown in Figure 1.

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Box 1

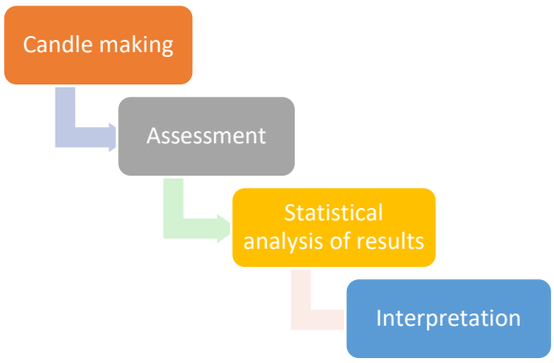

Figure 1
Research project methodology
Source: Own elaboration

Candle Making

Oil collected from various establishments dedicated to selling Mexican snacks was used to make the candles. Using burnt oil or oil from flour is not recommended because it is more difficult to eliminate the smell. The oil receives a previous treatment using the cold decantation method to separate the residues from frying. This process consists of adding water to the oil previously filtered in a funnel using a mesh instead of filter paper, shaking and letting it rest until the separation of the phases is observed. The oil was frozen, and after, the oil was separated by decantation free of impurities. Due to the rancid smell of these oils, it is necessary to deodorize the oil samples using granulated activated carbon (Bravo-Bonete, 2023).

Three batches of 200 gr candles were made with the treated oil. The proportions were selected by taking as a reference those mentioned in previous studies (Aquino-Rivera et al., 2021; Arriols, 2022; Bravo-Bonete, 2023). The first was 60% recycled oil and 40% low melting point soy wax; the second was 70%: 30%. Each batch consists of 6 candles (Table 1). The mixtures were prepared as shown in Table 1.

Box 2

Table 1
Proportion of ingredients used in the manufacture of scented candles

Batch	Waste oil (%)	Soy wax (%)
1	60	40
2	70	30
3	80	20

Source: Own elaboration

The candle-making process is as follows (figure 2):

1. Weigh the ingredients based on the proportions mentioned above.

2. Melt the wax at a temperature that does not exceed 50°C because this would cause the wax to evaporate, generating a loss of this input in production. The temperature was checked with an alcohol thermometer.

3. At the same time, heat the vegetable oil, which went through a waste removal process, to approximately the same temperature as the wax to prevent creating a vacuum in the container's center when it hardens.

4. Once both materials are at the same temperature, add the soy wax to the oil until it is entirely homogenized, monitoring the temperature during the process.

5. Add the colorant and the essence once the corresponding temperature has been checked. The importance of this step lies in the fact that the essence can evaporate when it exceeds 50°C, losing its aroma and, consequently, using more quantity than required.

6. Prepare a container with a wick, and pour the mixture once it has reached 30°C.

7. Cool until hardened in a space where no strong wind currents or dirt could be impregnated in the wax solidification process.

8. Labeling with the brand logo and safety specifications, considering the American Society for Testing and Materials (ASTM) regulations, especially ASTM-F2058-07-2021: Standard specification for fire safety labeling of candles. This standard covers the requirements for placing fire safety information on candle sales units and is mainly applied to retailers and distributors (ANSI, 2022).

9. Evaluation of the finished product.

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Box 3

Figure 2
Aromatic candle manufacturing process

Product evaluation

Safety tests help ensure the quality of candles. Some tests recommended for their performance are the burning compartment, stability, soot/smoke, consumption time, and flame height (Intertek, 2024). For the evaluation of the product, seven tests were applied to observe its quality, which are the following:

Test 1. Visual and physical inspection. A scale was used to weigh the candles one by one to measure the amount of wax burned during each burning cycle. The color, texture, impurity check, and wick integrity were evaluated using a specific scale. Pressure was applied to measure hardness with the fingers in different sections. In addition, cracks, openings, and the integrity of the wick were checked in each candle. Figure 3 shows the scale used for each of these parameters.

Test 2. Burn Times. It is defined as evaluating the performance of finished candles from the first to the last burn to ensure that they burn regularly, do not produce abnormal amounts of soot, and are safe for the end user (CandleScience, 2024). Candles should be burned in 4-hour cycles placed at a minimum distance of 20 cm (8 inches) (Bravo-Bonete, 2023). The wick needs to be trimmed to 6 mm (1/4 inch) with sharp scissors before lighting the wick.

Measurements of the diameter of the melted wax around the wick and the pool depth were taken every hour with a vernier caliper, and the candle was extinguished after each 4-hour cycle (CandleScience, 2024). With those mentioned above, the duration of each candle was also determined. Likewise, the amount of wax burned per hour was measured to analyze how long it takes for the candle to burn that amount of wax (ANSI, 2021).

Box 4

Figure 3
Value scale for the Visual and Physical Inspections test

Source: Own elaboration

Test 3. Candle pool. Checks were made every hour during the burning cycle to assess the candle pool diameter. By the third hour, it must be at least 6 mm from the edge of the container, but after 4 hours, it must cover the entire diameter of the pool or leave a small margin of distance to consider. The depth of the candle pool must be between 6 and 13 mm, although it can be influenced by various factors such as the number of wicks or type of wax. The pool for the first burn cycles may not completely reach the edges, but for burn cycles greater than or equal to four, the diameter of the container should already be complete (CandleScience, 2024).

Test 4. Flame height. This test was performed at room temperature in a clean, closed room with no drafts. The candles were placed 10 cm apart from each other. The flame height was measured on the lit candles at the beginning and end with a vernier caliper.

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Flame behavior was recorded every hour until the end of the 4-hour cycle. For a standard candle, the height is one inch (approx. 2.5 cm) high; however, some flames up to two inches (approx. 5 cm) can be considered normal (Bravo-Bonete, 2023). Throughout the burn cycle, the flame tends to be stable, with slight disturbances. As the wax content decreases, heat tends to accumulate in the candle pool but in the center of it, so the flame is expected to move more during combustion (CandleScience, 2024).

Test 5. Sensory rating scale. In this case, the perception of the aroma that people feel when smelling the candle was evaluated, where the expected parameters will depend on the objectives that the manufacturer wants to achieve and with their chosen scale. In this test, five people with no condition that affected their sense of smell participated. They evaluated the aroma, intensity, uniformity, and persistence of each candle from the different groups, following a scale from 1 to 5, with their eyes closed so they did not know which batch they were evaluating (Fischer, 2020).

Test 6. Combustion afterglow check. The check was performed at the end of each burning cycle, before extinguishing the candles with the same container lid and then removing the lid. The time was measured in seconds to determine the duration in which the wick core completely extinguished without releasing smoke. A value close to 1s is the best in the field of accident prevention and indicates better candle quality (CandleScience, 2024).

Test 7. Combustion and afterglow smoke. This test was performed in a clean room free of air currents at room temperature. The load of certain aromatic oils or poor oil treatment indicates poor quality (CandleScience, 2024). Four aspects were evaluated in this test: quantity, color, smoke persistence, and soot residue. The scales were used from 1 to 5, where 1 was the lowest and 5 was the highest. Table 2 shows the scale used to evaluate this test.

Box 5

Table 2
Value scale for the Combustion and Afterglow Smoke

Amount of smoke	Smoke color	Smoke persistence	Soot residue
1= Null 2= Very little 3=Medium 4= Faor 5= Large	1= White 2=Light gray 3=Gray 4=Dark gray 5= Black	1= Nothing 2= very light 3=Slightly 4= Moderately 5= Persistent	1= Yes 2= No

Source: Own elaboration

Statistical Analysis of the Results

The average results of the different tests are shown in Table 3.

Box 6

Table 3
Results obtained from quality tests

No. Off batch	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
1	3.4000	1.2563	3.9125	.9625	4.0000	2.3750	1.5000
1	2.2000	1.1813	4.0375	1.1125	3.8750	3.2500	1.6250
1	2.8000	1.2	4.1500	1.0625	3.8750	2.5000	1.6875
1	3.0000	1.5625	4.1375	1.0375	4.0000	2.1250	1.5000
1	2.2000	1.3125	4.1500	.9875	4.0000	3.0000	1.6875
1	3.4000	1.2563	4.2500	1.1500	3.7500	2.0000	1.8125
2	3.4000	2.7331	3.3500	1.0175	3.6250	5.5600	2.1250
2	3.0000	2.4813	3.8125	1.2375	3.8750	3.7850	2.2500
2	3.8000	2.4438	3.6500	1.0800	4.2500	4.3000	1.9375
2	3.4000	2.6438	4.0250	.9625	4.0000	5.0775	2.1250
2	3.4000	2.5938	3.7250	1.4125	3.5000	4.5075	2.2500
2	3.0000	2.5688	3.7875	1.1250	2.7500	5.1825	2.2500
3	3.8000	1.6438	3.5500	1.3000	3.5000	3.2075	1.9375
3	3.0000	1.8625	3.3625	1.1750	3.5000	3.3000	1.6875
3	3.0000	1.8438	3.4625	1.2750	3.1250	3.0025	1.6875
3	3.4000	1.7063	3.4375	1.3500	3.3750	3.2725	1.6875
3	3.0000	1.8063	3.1625	1.1125	3.1250	3.4600	1.5625
3	3.2000	1.8938	3.3750	1.2125	3.3750	3.0575	1.6250

Source: Own elaboration

The average obtained from the sum of these attributes was considered for the tests where several parameters are evaluated, such as 1, 3, 5, and 7.

The combustion time used in the table is about the amount of wax burned in a period of one hour. The amount of wax burned in cm in a cylindrical container of 6.5 cm in diameter by 6 cm in height is measured to do this. The average lifespan of the candles was 38, 42, and 41. This data was obtained by burning three candles from each batch in their entirety under similar conditions to see the durability of the candle.

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The combustion time, the candle pool, and the flame height are in cm, the combustion afterglow check is in seconds, and the visual and physical inspection, the sensory rating scale, and the combustion and post-combustion smoke are in scales.

The results obtained were analyzed using the MANOVA statistical model, a technique derived from multivariate analysis or multivariate statistics that estimates the differences between the means of several categories or treatments by jointly comparing the observed dependent variables. The categories are given by the criteria defining different states, pathological conditions, human groups, doses, and treatments, to name a few (Vargas, Muñoz, Paba, & Ordoñez, 2020).

The necessary conditions to use MANOVA are:

a) Several treatments are defined by the degree, absence, or presence of an Independent Variable (Idem)

b) Within each treatment, there are several individuals or subjects (Idem)

c) The measurements for each individual or subject are independent. A MANOVA is performed when the researcher designs an experimental situation with several treatments to evaluate hypotheses concerning the variance of group performances in two or more quantitative dependent variables (Idem)

In this research, seven quality tests were performed. However, to reduce collinearity and singularity problems in the covariance matrices and comply with the assumption of independence of observations, those related to each other were grouped. These groups were visual and physical inspection and sensory rating scales. Evaluation scales were used in both tests, facilitating the merging and giving rise to a new test called physical and sensory characteristics (Test 1). The second merge was between the combustion time and candle puddle tests. These tests were measured in cm concerning the candle wax. Both tests were merged into the wax analysis (Test 2), decreasing the dependent variables to five (Table 4).

Box 7

Table 4

Results obtained from 5 quality tests

batch	Test 1	Test2	Test 3	Test 4	Test 5
1	3.7000	2.5844	0.9625	2.3750	1.5000
1	3.0375	2.6094	1.1125	3.2500	1.6250
1	3.3375	2.6750	1.0625	2.5000	1.6875
1	3.5000	2.8500	1.0375	2.1250	1.5000
1	3.1000	2.7313	0.9875	3.0000	1.6875
1	3.5750	2.7532	1.1500	2.0000	1.8125
2	3.5125	3.0416	1.0175	5.5600	2.1250
2	3.4375	3.1469	1.2375	3.7850	2.2500
2	4.0250	3.0469	1.0800	4.3000	1.9375
2	3.7000	3.3344	0.9625	5.0775	2.1250
2	3.4500	3.1594	1.4125	4.5075	2.2500
2	2.8750	3.1782	1.1250	5.1825	2.2500
3	3.6500	2.5969	1.3000	3.2075	1.9375
3	3.2500	2.6125	1.1750	3.3000	1.6875
3	3.0625	2.6532	1.2750	3.0025	1.6875
3	3.3875	2.5719	1.3500	3.2725	1.6875
3	3.0625	2.4844	1.1125	3.4600	1.5625
3	3.2875	2.6344	1.2125	3.0575	1.6250

Own elaboration

Model Assumptions

Multivariate Normality. This assumption is identified with the requirement that the p-independent variables present a multivariate normal distribution in each group (Bray & Maxwell, 1985). A normality test was performed to verify this assumption. The results obtained can be observed in Figure 4.

In this test, two methods are observed, Kolmogorov-Smirnov and Shapiro-Wilk, because the amount of data is less than 50. The Shapiro-Wilk statistic results were chosen since these values are significant (P> 0.5). Therefore, there is sufficient statistical evidence not to reject the null hypothesis and confirm that the data meets the normality assumption.

Box 8

Pruebas de normalidad

	Número de lote de cada vela	Kolmogorov-Smirnov[a]			Shapiro-Wilk
		Estadístico	gl	Sig.	Estadístico
Prueba de Calidad 1	1	.183	6	.200*	.934
	2	.268	6	.200*	.940
	3	.175	6	.200*	.914
Prueba de Calidad 2	1	.156	6	.200*	.963
	2	.234	6	.200*	.894
	3	.201	6	.200*	.904
Prueba de Calidad 3	1	.149	6	.200*	.967
	2	.201	6	.200*	.940
	3	.166	6	.200*	.980
Prueba de Calidad 4	1	.200	6	.200*	.931
	2	.199	6	.200*	.967
	3	.162	6	.200*	.963
Prueba de Calidad 5	1	.201	6	.200*	.912
	2	.276	6	.170	.801
	3	.366	6	.012	.822

Figure 4

Normality tests. Retrieved from IBM SPSS Statistics

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Homogeneity of covariances. MANOVA examines all elements of the variance-covariance matrix of the p-dependent variables. Therefore, it tests the equality of the components of said matrix (Friendly & Sigal, 2018).

In the MANOVA analysis, the covariance matrices within each treatment must be homogeneous. This test allows to reject or not reject the null hypothesis. The results of the Box test are shown in Figure 5.

Box 9

Prueba de Box de la igualdad de matrices de covarianzas[a]

M de Box	56.033
F	.904
gl1	30
gl2	712.958
Sig.	.617

Figure 5

Table of results of the equality test of covariance matrices taken from IBM SPSS Statistics

In the assumption of homogeneity of covariance matrices, the results obtained were a significance of 0.617 (P>0.05); therefore, it corroborates that there are no differences between the covariance matrices, and they are homogeneous, and homoscedasticity exists.

Linearity. The relationships between the independent and dependent variables must be linear. This linearity means that changes in the independent variables must lead to proportional changes in the dependent variables. The correlation table the SPSS Statistics program provided was interpreted to ensure linearity. The results obtained are shown in the figure 6

Box 10

Correlaciones

		Prueba de Calidad 1	Prueba de Calidad 2	Prueba de Calidad 3	Prueba de Calidad 4	Prueba de Calidad 5
Prueba de Calidad 1	Correlación de Pearson	1	.277	-.139	.027	.157
	Sig. (bilateral)		.265	.581	.916	.534
	N	18	18	18	18	18
Prueba de Calidad 2	Correlación de Pearson	.277	1	-.111	.724**	.849**
	Sig. (bilateral)	.265		.662	<.001	<.001
	N	18	18	18	18	18
Prueba de Calidad 3	Correlación de Pearson	-.139	-.111	1	-.007	.233
	Sig. (bilateral)	.581	.662		.978	.352
	N	18	18	18	18	18
Prueba de Calidad 4	Correlación de Pearson	.027	.724**	-.007	1	.787**
	Sig. (bilateral)	.916	<.001	.978		<.001
	N	18	18	18	18	18
Prueba de Calidad 5	Correlación de Pearson	.157	.849**	.233	.787**	1
	Sig. (bilateral)	.534	<.001	.352	<.001	
	N	18	18	18	18	18

**. La correlación es significativa en el nivel 0,01 (bilateral).

Figure 6

Table 1 of correlation results

Source: *Taken from IBM SPSS Statistics*

The linearity assumption was interpreted using the value p<.05 to measure the significance level under the argument that results can indicate that the quality tests mostly have a positive linear relationship (LR +). Therefore, there is sufficient evidence to confirm this assumption (table 5)

Box 11

Table 5

Interpretation of linearity between quality tests

	Test 1	Test 2	Test 3	Test 4	Test 5
T1		LR +	LR +	LR +	LR +
T2	LR +		LR +	no linear relationship	no linear relationship
T3	LR +	LR +		LR +	LR +
T4	LR +	no linear relationship	LR +		no linear relationship
T5	LR+	no linear relationship	LR +	LR +	

Source: Own elaboration

Absence of multicollinearity. Multicollinearity refers to the presence of high correlations between independent variables. It is important to avoid perfect multicollinearity, where one independent variable can be perfectly predicted from another. This situation can lead to unstable parameter estimates and unreliable results. The Minitab program was used to check this assumption. The results obtained are presented in figure 7.

Box 12

Coeficientes

Término	Coef	EE del coef.	Valor T	Valor p	VIF
Constante	-0.17	3.05	-0.05	0.958	
Prueba 1	0.365	0.526	0.69	0.501	1.17
Prueba 2	-1.40	1.30	-1.07	0.305	5.85
Prueba 3	4.19	1.43	2.93	0.013	1.80
Prueba 4	0.753	0.238	3.16	0.008	3.10
Prueba 5	-1.40	1.51	-0.93	0.372	8.04

Figure 7

VIF variance inflation factor

Source: *Retrieved from Minitab.*

This assumption is interpreted through the variance inflation factor (VIF), which measures the increase in the variance of a regression parameter and whether the exploratory variables are related (table 6).

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Box 13

Table 6

Variance Inflation Factor

Test	VIF	Reference	Interpretation
1	1.17	1<VIF<5	The variables are slightly related. But it does not affect the model.
2	5.85	5<VIF<10	The variables are moderately related. There is a moderate risk of multicollinearity, that is, there is a possibility that the regression parameters do not sean estimados apropiadamente.
3	1.80	1<VIF<5	The variables are slightly related. But it does not affect the model.
4	3.10	5<VIF<10	We say that the variables are moderately related. There is a moderate risk of multicollinearity.
5	8.04	5<VIF<10	The variables are moderately related. There is a moderate risk of multicollinearity.

Source: Own elaboration

The conclusion was that there is no multicollinearity between variables, thus fulfilling this assumption.

MANOVA Analysis

Levene's Test

Levene's test is used to test the null hypothesis that the samples to be compared come from a population with the same variance. In this case, possible differences in variance only occur by chance since each sample has minor differences. The results obtained from this test are indicated in figure 8.

Box 14

Prueba de igualdad de Levene de varianzas de error[a]

		Estadístico de Levene	gl1	gl2	Sig.
Prueba de Calidad 1	Se basa en la media	.347	2	15	.712
Prueba de Calidad 2	Se basa en la media	.717	2	15	.504
Prueba de Calidad 3	Se basa en la media	2.008	2	15	.169
Prueba de Calidad 4	Se basa en la media	5.183	2	15	.019
Prueba de Calidad 5	Se basa en la media	.066	2	15	.936

Figure 8

Levene's Equality Test of error variances
Source: Retrieved from IBM SPSS Statistics

In the test of homogeneity of variances (Levene's test of equality of error variances), the interpretation is based on the mean. The significance values for quality tests 1, 2, 3, and 5 are p>.05, therefore, there is no significant difference between the variances of these tests. However, for quality test 4, the value p<.05 indicates significant differences in this test, so it is concluded that the variances are not homogeneous because at least one is different.

Multivriate tests

In the general linear model, the focus is on hypothesis testing. The Figure 10 multivariate tests show four reference statistics that can be considered to interpret the results. In this case, Wilkins' lambda was used to obtain a value of 0.001, less than the associated p-value of 0.05; therefore, the multivariate contrasts indicate that there are differences in the interaction of the dependent variables (Quality tests) according to the dependent variable (the batch number), this means that rejecting the null hypothesis, consequently, there are significant differences between the batches in at least one of the quality tests (Figure 9)

Box 15

Pruebas multivariante[a]

Efecto		Valor	F	gl de hipótesis	gl de error	Sig.	Eta parcial al cuadrado	Parámetro de no centralidad	Potencia observada[d]
Intersección	Traza de Pillai	1.000	5841.232[b]	5.000	11.000	<.001	1.000	29206.158	1.000
	Lambda de Wilks	.000	5841.232[b]	5.000	11.000	<.001	1.000	29206.158	1.000
	Traza de Hotelling	2655.105	5841.232[b]	5.000	11.000	<.001	1.000	29206.158	1.000
	Raíz mayor de Roy	2655.105	5841.232[b]	5.000	11.000	<.001	1.000	29206.158	1.000
No_de_lote	Traza de Pillai	1.613	10.009	10.000	24.000	<.001	.807	100.088	1.000
	Lambda de Wilks	.015	15.967[b]	10.000	22.000	<.001	.879	159.669	1.000
	Traza de Hotelling	24.377	24.377	10.000	20.000	<.001	.924	243.772	1.000
	Raíz mayor de Roy	22.472	53.933[c]	5.000	12.000	<.001	.957	269.665	1.000

a. Diseño : Intersección + No_de_lote
b. Estadístico exacto
c. El estadístico es un límite superior en F que genera un límite inferior en el nivel de significación.
d. Se ha calculado utilizando alpha = .05

Figure 9

Multivariate tests
Source: Retrieved from IBM SPSS Statistics

Inter-subject effects tests

This analysis evaluates the individual interaction of the independent variables (batch number) on each dependent variable (quality tests). Thus, it evaluates whether the means of the data obtained from the quality tests show a significant difference between the batch number (different concentrations of residual oil).

The test indicates that quality tests 2, 3, 4, and 5 show significant differences. However, for test 1, there are no differences, concluding that the concentration of residual oil affects the quality of the candles in terms of performance but not the physical and sensory characteristics.

Box 16

Pruebas de efectos inter-sujetos

Origen	Variable dependiente	Tipo III de suma de cuadrados	gl	Media cuadrática	F	Sig.	Eta parcial al cuadrado	Parámetro de no centralidad	Potencia observada[c]
No_de_lote	Prueba de Calidad 1	.142	2	.071	.813	.462	.098	1.627	.163
	Prueba de Calidad 2	1.055	2	.527	63.928	<.001	.895	127.855	1.000
	Prueba de Calidad 3	.103	2	.052	3.912	.043	.343	7.824	.612
	Prueba de Calidad 4	15.150	2	7.575	32.551	<.001	.813	65.102	1.000
	Prueba de Calidad 5	.970	2	.485	31.493	<.001	.808	62.986	1.000

Figure 10

Tests for between-subjects effects
Source: Taken from IBM SPSS Statistics

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Post Hoc Tests

Post hoc tests determine the differences between groups of the independent variables (batch numbers) using significance values below .05. In the results of multiple comparisons, two analyses can be seen for each dependent variable, Bonferroni and Games-Howell, which was used for this work. A value p<0.5 results in homogeneity of variances not being met. Therefore, values lower than this indicate that there is a difference; on the contrary, higher values mean that there is no significant difference.

In quality test 1, there are no significant differences, which indicates that none of the three lots have significant differences in physical and sensory characteristics.

Box 17

Test 1

Comparaciones múltiples

Variable dependiente	(I) Número de lote de cada vela	(J) Número de lote de cada vela	Diferencia de medias (I-J)	Desv. Error	Sig.	Intervalo de confianza al 95% Límite inferior	Límite superior
Games-Howell	1	2	-.125000	.1884144	.790	-.651364	.401364
		3	.091667	.1409664	.797	-.296863	.480197
	2	1	.125000	.1884144	.790	-.401364	.651364
		3	.216667	.1785843	.478	-.292785	.726118
	3	1	-.091667	.1409664	.797	-.480197	.296863
		2	-.216667	.1785843	.478	-.726118	.292785

Figure 11

Tests for between-subjects effects
Source: Taken from IBM SPSS Statistics

In quality test 2, a significance of p<0.5 was obtained between batch 1 and batch 2, and between batch 2 and 3, observing significant differences in wax analysis.

Box 18

Test2

Comparaciones múltiples

Variable dependiente	(I) Número de lote de cada vela	(J) Número de lote de cada vela	Diferencia de medias (I-J)	Desv. Error	Sig.	Intervalo de confianza al 95% Límite inferior	Límite superior
Games-Howell	1	2	-.450683*	.0593780	<.001	-.613640	-.287726
		3	.108325	.0470671	.111	-.025292	.241942
	2	1	.450683*	.0593780	<.001	.287726	.613640
		3	.559008*	.0500795	<.001	.415355	.702662
	3	1	-.108325	.0470671	.111	-.241942	.025292
		2	-.559008*	.0500795	<.001	-.702662	-.415355

Figure 12

Post Hoc Quality Test 2

Quality test 3 also presents a p-value less than 0.05 in batches 1 and 3; therefore, it suggests a significant difference in the flame height of these batches (Figure 13).

Box 19

Prueba 3

Comparaciones múltiples

Variable dependiente	(I) Número de lote de cada vela	(J) Número de lote de cada vela	Diferencia de medias (I-J)	Desv. Error	Sig.	Intervalo de confianza al 95% Límite inferior	Límite superior
Games-Howell	1	2	-.087083	.0729957	.494	-.303192	.129026
		3	-.185417*	.0461448	.007	-.312695	-.058138
	2	1	.087083	.0729957	.494	-.129026	.303192
		3	-.098333	.0757674	.437	-.317051	.120384
	3	1	.185417*	.0461448	.007	.058138	.312695
		2	.098333	.0757674	.437	-.120384	.317051

Figure 13

Post Hoc Quality Test 3

Quality test 4 presents a p<0.05 in all batches, indicating significant differences in afterglow time. (Figure 14)

Box 20

Prueba 4

Comparaciones múltiples

Variable dependiente	(I) Número de lote de cada vela	(J) Número de lote de cada vela	Diferencia de medias (I-J)	Desv. Error	Sig.	Intervalo de confianza al 95% Límite inferior	Límite superior
Games-Howell	1	2	-2.193750*	.3341657	<.001	-3.121584	-1.265916
		3	-.675000*	.2120449	.042	-1.321106	-.028894
	2	1	2.193750*	.3341657	<.001	1.265916	3.121584
		3	1.518750*	.2759155	.004	.657244	2.380256
	3	1	.675000*	.2120449	.042	.028894	1.321106
		2	-1.518750*	.2759155	.004	-2.380256	-.657244

Figure 14

Post Hoc Quality Test 4

Finally, in quality test 5, a significance of .001 was obtained between batches 1 and 2 and batches 2 and 3. Therefore, there is a significant difference in combustion and post-combustion smoke between these batches (Figure 15)

Box 21

Prueba 5

Comparaciones múltiples

Variable dependiente	(I) Número de lote de cada vela	(J) Número de lote de cada vela	Diferencia de medias (I-J)	Desv. Error	Sig.	Intervalo de confianza al 95% Límite inferior	Límite superior
Games-Howell	1	2	-.520833*	.0706493	<.001	-.714513	-.327153
		3	-.062500	.0718675	.670	-.259592	.134592
	2	1	.520833*	.0706493	<.001	.327153	.714513
		3	.458333*	.0724689	<.001	.259639	.657028
	3	1	.062500	.0718675	.670	-.134592	.259592
		2	-.458333*	.0724689	<.001	-.657028	-.259639

Figure 15

Post Hoc Quality Test 5

Significant differences were found in most of the quality tests, which is sufficient evidence to reject our null hypothesis. Therefore, the concentration of residual vegetable oil affects the quality of the candles.

Conclusions

For this experimental project, the main objective was to determine whether the concentration of recycled cooking oil in the production of candles affects their quality. Quality was evaluated through 7 tests in four burning cycles (16 hours), and sufficient statistical evidence was obtained to submit it to the MANOVA analysis.

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In addition, the five assumptions required for this statistical analysis were met, which guaranteed, with a confidence level of 95%, the certainty and reliability of the results obtained from the data collected.

The multivariate test indicates that there is a significant difference between the results of the quality tests of each batch of candles and the concentration used to manufacture the candles. Therefore, the concentration of recycled cooking oil used in the production of Mexican snacks does affect the quality of the candles.

By stating that there are differences, it is necessary to determine which quality tests present differences between the batches of candles in a more specific way. When performing the inter-subject analysis, it was determined that the variation in the oil proportions causes variability in tests 2, 3, 4, and 5, and only test 1 does not show a difference. Moreover, the oil variation is reflected in the amount of wax burned, the diameter of the candle pool, the height of the flame, the time it takes for the wick to go out after the candle is extinguished, the characteristics of the smoke produced by the candle during combustion and after it is extinguished. However, the oil proportion does not affect physical qualities such as color intensity, texture, imperfections, and aroma intensity. Regardless of which batch is used, the quality of the aroma and its presentation will be the same.

Therefore, based on the results obtained, if the customer's perception is focused on the aroma generated by the candle, any of the three batches guarantees that the aroma and physical appearance are comparable to an aromatic candle from the market.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Ramos-González, Luz María. contribute with the idea, in the coordination of the Project, supervision in the experimental part and writing of the article.

Cruz-Orduña, María Inés, contribution with the analysis of the results, translation into English, support in the supervision of the experimental part of the project.

Vicente-Pérez, Brisia Joseline, contributed to the brainstorming that gave rise to the Project in the collection of oil, in the experimental part of the work.

Martínez-Velázquez, Víctor, support in the collection and treatment of the oil, also in the supervision of the experimental part, and in the final review of the writing of the article.

Availability of data and materials

The data supporting this study's findings are available from the corresponding author, [R-G.L.M.], upon reasonable request.

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Abbreviations

LR Linear relationship

MANOVA Multivariate Analysis of Variance

VIF Variance Inflation Factor

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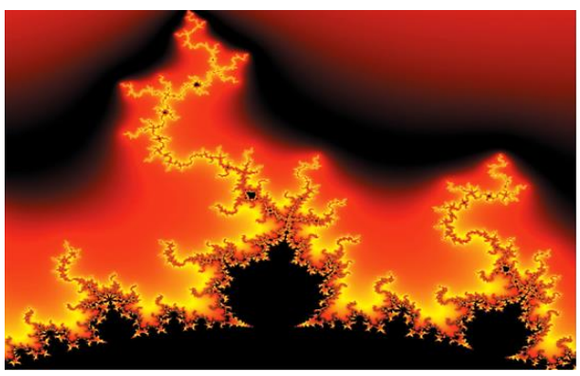

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