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Selection of material for manufacturing nozzles used in plastic hose extrusion process

Selección del material para la fabricación de las boquillas utilizadas en el proceso de extrusión de mangueras plásticas

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Abstract: A procedure is presented for selecting the material intended for the manufacture of nozzles in a plastic hose extrusion process, with the objective of formulating and applying a material selection procedure for the manufacture of extrusion nozzles at the Ernesto Che Guevara Industrial Company in Santiago de Cuba. The study applies reverse engineering to a nozzle that has been in operation for more than 20 years, combining optical emission spectrometry to determine the chemical composition of its components (mandrel, adapter, and die) with subsequent correlation to international DIN and AISI standards to identify the corresponding steels. Based on this identification, the thermal, mechanical, wear and corrosion resistance properties are analyzed, as well as machinability, cost, and availability within the Cuban industrial context. As a result, steel W.1.2738 was validated for the mandrel and steel AISI 1035 for the adapter and die, demonstrating their suitability after more than two decades of operation without significant failures. Substitute materials are also proposed for cases involving more demanding service conditions. The developed procedure provides a systematic and replicable tool for selecting extrusion nozzle materials in situations where information from the original manufacturer is not available or when optimization of existing designs is required.

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Keywords: stells, machine desing, polymers, industrial processes, material resistance, plastic transformation

Resumen: Se presenta un procedimiento para la selección del material para la fabricación de boquillas en un proceso de extrusión de mangueras plásticas en la Empresa Industrial Ernesto Che Guevara, de Santiago de Cuba. El estudio emplea ingeniería inversa aplicada a una pieza con más de 20 años de explotación, combinando espectrometría de emisión óptica para determinar la composición química de sus componentes (mandril, adaptador y dado) y la correlación posterior con normas internacionales DIN y AISI para identificar los aceros correspondientes. A partir de esta identificación se analizan las propiedades térmicas, mecánicas, de resistencia al desgaste y a la corrosión, así como aspectos de maquinabilidad, costo y disponibilidad en el contexto industrial cubano. Como resultado, se valida el acero W.1.2738 para el mandril y el acero AISI 1035 para el adaptador y el dado, demostrando su idoneidad tras más de dos décadas de explotación sin fallos significativos, y se proponen materiales sustitutos para escenarios de mayores exigencias de servicio. El procedimiento desarrollado proporciona una herramienta sistemática y replicable para seleccionar materiales de boquillas de extrusión en condiciones donde no se dispone de información del fabricante original o se requiere optimizar diseños existentes.

Palabras claves: aceros, diseño de máquina, polímeros, procesos industriales, resistencia de materiales, transformación de plástico

1. Introduction

Plastic hoses manufacturing is fundamental in various sectors. Extrusion machines must be adapted to markets demanding mass customization, sustainability, and energy efficiency (Benites *et al*., 2024; González *et al.,* 2025). Within this system, the nozzle, part that shapes the plastic into a tubular or cylindrical form, is a strategic element whose management redefines industrial competitiveness (Saengow, *et al*., 2015).

Nozzles are essential in extrusion machines for manufacturing hoses. Its design and dimensions must be adequate to ensure a constant and uniform flow of material, avoiding stagnation or product defects (Bouvier & Campanella, 2014). It allows adapting the hose shape and dimensions according to technical specifications, upholds product quality by ensuring the molten plastic is correctly shaped, facilitates the production of different types of hoses, and prevents manufacture problems such as blockages or variations in hose wall thickness (Kovalenco *et al*., 2014).

Nozzle material selection is a critical factor impacting the efficiency, quality, production costs, and equipment's lifespan. Nozzles must be compatible with the plastic being extruded and capable of withstanding high temperatures without deforming or degrading (Beltrán & Marcilla, 2012; Álvarez, 2021).

Steel is the most commonly used material for manufacturing injection molds. However, this material must possess properties that establish the finished part conditions, such as resistance to crushing and stretching, polishability, toughness, minimal imperfections, optimal thermal conductivity, recovery capacity, and resistance to chemical agents. Therefore, it is essential to clarify the type of mass to be prepared, the necessary heat treatment, the block casting method, and the type of mechanical stress magnitude (Tang, 2024). This is achieved by combining the analysis of service, process, and cost-benefit requirements.

Selection criteria are practical and aligned with industry standards, prioritizing mechanical, thermal, and chemical resistance to ensure durability in extrusion molds. However, many overlook specific quantification by using standards such as DIN or AISI, which are essential to compare steel grades in critical designs.

Ernesto Che Guevara Industrial Company in Santiago de Cuba manufactures ½” (12.5 mm) hoses with a plastic extrusion machine donated by Italy. Diversifying hose diameters is mandatory, however, the lack of extrusion nozzles for these cases precludes their production.

It is necessary to select the appropriate material to fabricate other nozzles. Material selection using the reverse engineering method ensures the suitable material identification for the extrusion process when manufacturer specifications are lacking or extrusion process parameters are unknown due to an absence of measuring instruments.

The aim of this work is to formulate and apply a material selection procedure to manufacture nozzles for the plastic hose extrusion process, at Ernesto Che Guevara Industrial Company, in Santiago de Cuba, by using the reverse engineering method.

Materials and Methods

2.1. Plastic extrusion nozzles

Nozzles are critical elements in the extrusion process of thermoplastic polymers, acting as the final interface between the plastification system and the shaped product (Beltrán & Marcilla, 2012). Specifically designed for each profile geometry, nozzles determine the cross-section of the extrudate by imposing a defined flow configuration (Figure 1).

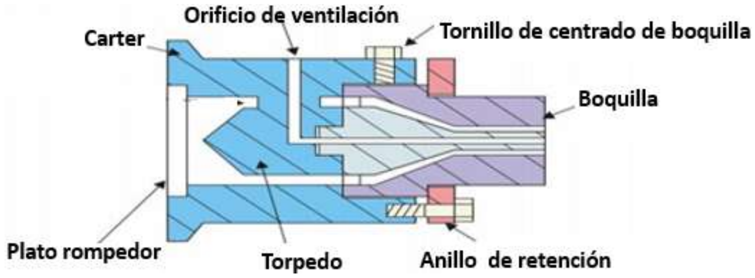

Figure 1. Head where a nozzle is inserted in the extrusion process (Beltrán & Marcilla, 2012).

A nozzle with more than 20 years of service (Figure 2), consisting of three components: adapter, mandrel, and die, was used. This part was in perfect technical condition at the time it was removed from the extrusion machine head.

Figure 2. Image of the nozzle used for the study.

2.2. Reverse engineering method

An optical emission spectrometer manufactured by Oxford Instruments was used in the study. It was employed to identify the materials of the different components and to determine the chemical composition of the material each nozzle component is made off.

2.3. Procedure for determining chemical composition with the optical emission spectrometer

1. Sample preparation: a 50 mm diameter nozzle was used. Its three components were polished with 1 mm grit sandpaper until an oxide-and-impurities-free surface was obtained. It was then placed on the electrode that generates a spark or electric arc.

2. Material excitation: The machine applied a high-energy electrical discharge onto the metal surface. The vaporization of a small amount of material generated a high-temperature plasma (thousands of degrees Celsius).

3. Characteristic light emission: atoms and ions in the plasma were excited and emitted light at specific wavelengths. For example: iron (Fe) emits at ~371.99 nm; aluminum (Al) at ~396.15 nm; carbon (C) at ~193.09 nm.

4. Detection and spectral analysis: a system of lenses and diffraction gratings separated the light into different wavelengths. Each spectral line intensity was measured with photodetectors (CCD or PMT). These intensities were compared with pre-established calibration curves to determine each element concentration.

2.4. Methodological procedure for nozzle material selection

The selection of the material for the nozzle components was carried out using a methodological procedure structured in stages, integrating reverse engineering, service analysis, and bibliographic and standards verification.

This procedure is represented schematically in a flowchart (Figure 3). The procedure is developed in 8 steps that can be integrated into three stages:

I. Diagnosis stage: characterization of the existing nozzle (1); analysis of service conditions (2).

II. Evaluation stage: sampling and chemical analysis (3); steel identification (4); bibliographic and catalog verification (5); cost and availability evaluation (6).

III. Selection stage: final material selection by component (8) and proposal of substitute materials.

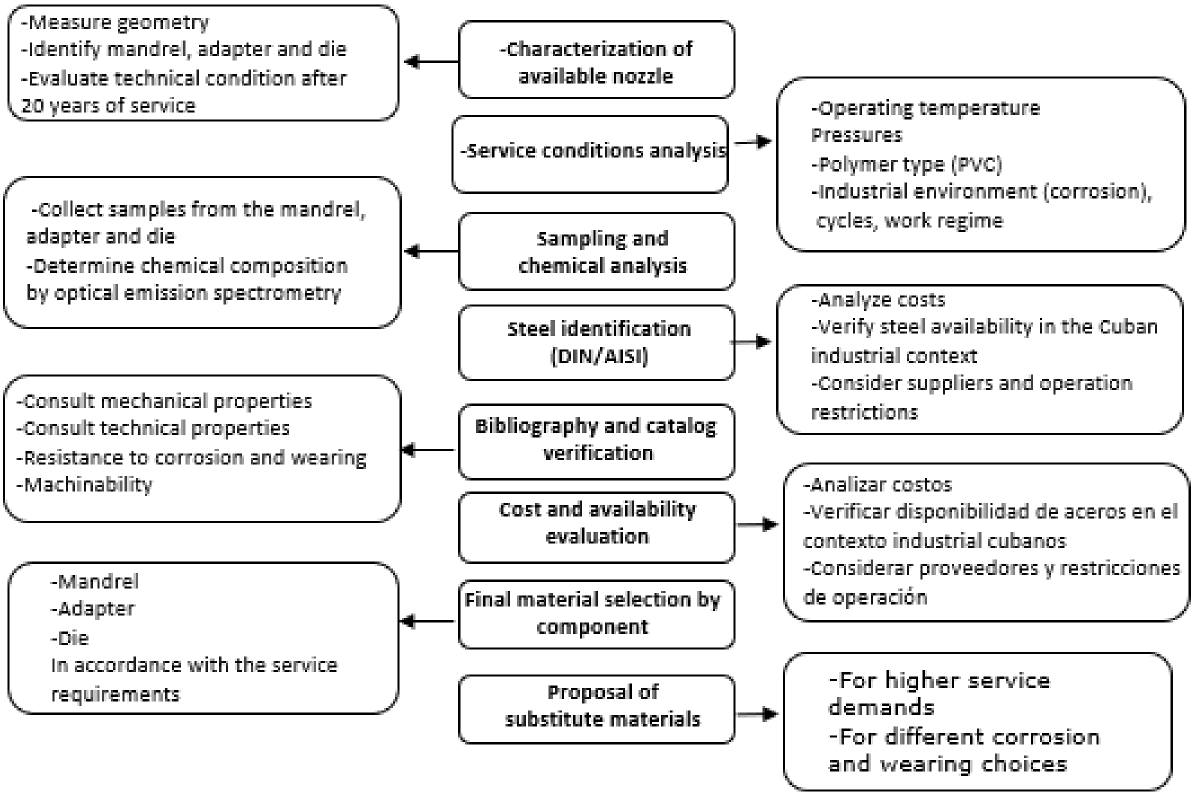

Figure 3. Flowchart for the selection of extrusion nozzle material using the reverse engineering method.

3. Results and Discussion

3.1. Results

The application of the reverse engineering procedure allowed the identification of the materials making up the three nozzle components (mandrel, adapter, and die) and the evaluation of their suitability for the plastic hose extrusion process at Ernesto Che Guevara Company.

3.1.1. Chemical composition of the nozzle material

Following the procedure, the chemical composition of each of the studied component was obtained (Table 1). These results constitute the basis for identifying the corresponding steels according to DIN and AISI standards and, consequently, select the ideal material for each nozzle component.

Table 1. Chemical composition of the mandrel, adapter, and die (wt.%)

Element	mandrel	adapter	die
Fe (Iron)	94,4	98,7	98,1
C (Carbon)	0,346	0,381	0,367
Si (Silicon)	0,760	0,720	0,230
Mn (Manganese)	1,51	0,70	0,718
P (Phosphorus)	0,0136	0,0090	0,0102
S (Sulfur)	0,0110	0,0348	0,0339
Cr (Chromium)	1,91	0,0891	0,0921
Mo (Molybdenum)	0,182	0,0245	0,0283
Ni (Nickel)	1,13	0,0969	0,104
Al (Aluminium)	0,0073	0,0132	0,0154
Co (Cobalt)	0,0146	0,0063	0,0064
Cu (Copper)	0,127	0,150	0,165
Nb (Niobium)	0,0005	0,0018	0,0019
Ti (Titanium)	0,0002	0,0141	0,0146
V (Vanadium)	0,0091	0,0036	0,0042
W (Tungsten)	0,0346	0,01	0,0183
Pb (Lead)	0,0082	0,0021	0,0051
Sn (Tin)	0,0098	0,0076	0,0096
B (Boron)	0,0010	0,0022	0,0021
Ca (Calcium)	0,0001	0,0001	0,0001
Zr (Zirconium)	0,0021	0,0027	0,0032
Zn (Zinc)	0,0036	0,0018	0,0020
Bi (Bismuth)	0,0296	0,0266	0,0263
As (Arsenic)	0,0117	0,0075	0,0084
Se (Selenium)	0,0153	0,0142	0,0134

3.1.2. Material characterization of the different nozzle components

Based on the chemical composition obtained and correlation with DIN standards, the material of the mandrel was identified as W.1.2738 steel. This steel is designed for the plastic mold industry, particularly medium-sized molds and tools requiring good machinability, dimensional stability, and adequate wear resistance under typical extrusion temperature working conditions. Table 2 presents the thermal properties and typical chemical composition values reported by technical literature and specialized suppliers.

Table 2. W.1.2738 steel characteristics

Thermal Properties		
Properties	Temperature ºC	UoM
Thermal conductivity	20	29 W/m K
Coefficient of thermal expansion	20-100	11.5 x 10-6 1/K
	100-200	11,9 x 10-6 1/K
	>300	12,6 x 10-6 1/K
Specific heat	-	470 J/kg ºC
Typical Chemical Composition Values		
C-0,4	Si-0,3	Cr-1,9
S-0,005	Mn-1,5	Mo-0,2
P-0,012	Ni-1	-

The thermal properties of W.1.2738 (intermediate thermal conductivity, moderate expansion coefficient, and good hardenability associated with its Ni and Cr content) contribute to maintaining the mandrel's dimensional stability under thermal gradients, reducing deformations and internal stresses during the molten polymer continuous flow. At the same time, its combination of achievable hardness after quenching and tempering, along with adequate machinability, supports its use in elements subjected to direct contact with molten plastic and frictional wear in the flow channel.

In the case of the adapter and die, the chemical analysis and comparison with AISI standard specifications indicate both components correspond to AISI 1035 steel. This medium-carbon steel is used in bearings, gears, and structural components requiring moderate mechanical strength, good toughness, and ease of machining at a relatively low cost. Table 3 shows its characteristics, including composition ranges and physical properties for applications subjected to mechanical loads, but with less severe thermal demands than the mandrel.

Table 3. AISI 1035 steel characteristics

Thermal Properties		
Properties	Temperature ºC	UoM
Thermal conductivity	20	
Coefficient of thermal expansion	20-100	
	100-200	
	>300	
Specific heat	-	
Typical Chemical Composition Values		
C-0,32-0,40	Mn-0,5-0,8	Ni<0,3
Si-0,17-0,37	P,S<0,04	-
Mn-0,5-0,8	Cr<0,25	-

The in-service performance observed in the original nozzle confirms that W.1.2738 steel is suitable for the mandrel and that AISI 1035 steel meets the adapter and die's mechanical and machinability requirements under the company's operating conditions.

3.1.3. Substitute materials

The mandrel is the part that comes into direct contact with the fluid. Using W.1.2738 steel properties as a reference, and the similarities in chemical composition, mechanical, and thermal properties, it was possible to propose substitute materials (Table 4).

Table 4. Substitute materials proposal (Qi, 2025)

Material	Advantages	Disadvantages
Stainless Steel AISI 304	- Corrosion resistance (ideal for non-corrosive plastics like polyethylene or polypropylene) - Withstands temperatures above 150°C. - Durability and easy maintenance.	Cost
Carbon Steel (with surface treatment)	- Low initial cost. - Can be surface treated (nitrided or coated) to improve corrosion and wear resistance.	- Without treatment is prone to oxidation and corrosion, especially with plastics that release acids (like PVC).
P20 Steel (pre-hardened)	- Good balance between cost and performance. - Adequate thermal resistance for temperatures up to 250-300°C. - Less expensive than stainless steel. - Low cost and easy machinability. - Anodizing improves its corrosion and wear resistance. - Suitable for temperatures up to 200°C.	- Lower wear resistance compared to steel. - Not recommended for abrasive or corrosive plastics.

3.2. Discussion

3.2.1. Material selection for nozzle manufacture

W 1.2738 steel chemical composition and properties demonstrate its suitability for direct contact with molten plastic, as it displays high thermal resistance, good conductivity, and mechanical stability, thus aligning with the technical requirements of the DIN standard (Ramos, 2012).

Molds dimensional stability is achieved through pre-hardened steels such as P20 or H13, with high thermal resistance and low thermal expansion, minimizing deformations caused by thermal gradients during the molten polymer continuous flow (Osswald & Hernández-Ortiz, 2018; Rauwendaal, 2014; Hernández *et al.,* 2024). Zhao *et al.* (2022) indicate that the friction coefficients of CVD coatings and H13 hot-work steel specimens are lower under hot extrusion conditions than at room temperature. A lower friction coefficient at high temperature implies less shear stress and less additional heat generation at the die-material interface, which reduces wear and the risk of surface defects in the extrusion.

AISI H13 steel is widely used in the manufacture of extrusion molds and other tools for hot shaping due to its toughness, high mechanical strength, and a hardness of approximately 56 HRC (Bejarano *et al.,* 2012).

1.2738 steel is a grade for plastic molds, used primarily for plastic injection molds. It can be considered an improved version of alloy 1.2311, with a 1 % of nickel content that positively affects hardenability. This steel is machinable, polishable, and suitable for texturing.

Virgamet (2025) exposes W 1.2738 steel properties: linear expansion coefficient: 11.2 * 10^{-6} m/(m·K); thermal conductivity: 35 W/(m·K); hardness (in soft annealed condition): < 235 HB and hardness (in quenched and tempered condition): < 51 HRC. He also provides the linear expansion coefficient thermal conductivity of 1.2738 steel at high temperature and in the quenched and tempered condition.

Heat treatment and machining (According to Virgamet, 2025)
- Forging: 1050-850 °C
- Rolling: 1050-850 °C
- Tempering: 840-870 °C
- Soft annealing: 710-740 °C

1.2738 steel, also known as P20+Ni or P20Ni, has several international equivalents. Table 5 shows its equivalents according to SteelPRO Group (2025).

Table 5. W 1.2738 steel equivalents

Standard	Equivalent Grade
GB	3Cr_2MnNiMo
ASTM/AISI	P20Ni
ISO	40CrMnNiMo 8-6-4
DIN	1.2738
JIS	PDS5S Steel
ISC	T25553

The chemical composition determined by spectrometry and correlated with DIN/AISI standards confirms W.1.2738 steel (mandrel) and AISI 1035 steel (adapter/die), whose thermal and mechanical properties —conductivity 29-35 W/mK, stability up to 300°C— concur with specialized literature on PVC extrusion molds (Virgamet, 2025; SteelPRO Group, 2025). This selection aligns with established industrial practices such as the use of pre-hardened steels of the P20+Ni type for direct contact with molten polymers (Osswald & Hernández-Ortiz, 2018).

The result guarantees, with a high degree of reliability, the recommendation to use W 1.2738 steel, according to DIN standard, or P20Ni steel, according to ASTM/AISI, for manufacturing dies for nozzles of different diameters. It also highlights the disadvantage of using other steels commonly used in mold manufacturing, such as AISI H13.

As for the adapter and die, AISI 1035 steel meets the moderate mechanical characteristics, good workability, and necessary strength for those parts that, although not in direct contact with the molten plastic, support significant mechanical loads. In the case of AISI 1035 steel, conventional quenching and tempering regimes for medium-carbon steels can be applied to adjust hardness and toughness to service requirements. Table 6 shows a typical heat treatment regime recommended for this steel, as it is suitable for components subjected to moderate mechanical loads in PVC extrusion processes.

Table 6. Typical quenching and tempering regime for AISI 1035 steel (Qi, 2025)

Stage	Parameter	Typical Range
Austenitizing	Temperature	840–870 °C
	Holding time	30–60 min (depending on section)
Quenching	Cooling medium	Water or quenching oil
	Exit temperature	Room Temperature
Tempering	Temperature	500–600 °C
	Holding time	60–120 min
Resulting Property	Expected hardness	≈ 180–220 HB

Regarding machinability, AISI 1035 is usually supplied in a rolled or normalized condition with hardnesses in the range of 150–190 HB, allowing lathing, drilling, and milling operations with hard metal or HSS tools at moderate cutting speeds. Goyal *et al.* (2022) consider that the medium hardness and good machining response combination reduces manufacturing times and tool costs, which benefits adapters and dies where geometric and dimensional finish is critical, but thermal demands are lower than mandrel's. Considering these components are not in direct contact with the molten polymer, prioritizing machinability and cost over maximum wear resistance is consistent with the function they perform in the nozzle.

AISI 1035 is a medium-carbon steel (approximately 0.35 % C). It is considered suitable for components such as dies and adapters in extrusion nozzles due to its strength, toughness, and machinability balance. It offers typical tensile strength of 585-660 MPa and good ductility (17-23 % elongation), allowing it to withstand moderate loads and wear stresses in plastic or metal extrusion processes, where dimensional precision after heat treatments is required (Jiménez-Lugo *et al.,* 2022; Velepucha *et al.,* 2023).

AISI 1035 steel exhibits moderate corrosion resistance, especially under atmospheric conditions. However, it is susceptible to pitting corrosion in chloride-bearing environments; besides, it should not be used in acidic conditions without protective coatings. Compared to stainless steels like 304 or 316, 1035 steel corrosion resistance is significantly lower, making it less suitable for applications in marine or highly corrosive environments (Liu *et al.,* 2015).

In PVC extrusion processes, the polymer can release HCl and other chlorinated compounds, especially under thermal degradation conditions, which can accelerate the corrosion of carbon steels like AISI 1035 if coatings or proper maintenance practices are not employed. In the analyzed case, the actual operating conditions (controlled temperatures, production and cleaning cycles, absence of highly aggressive atmospheres) and the possibility of applying coatings or surface treatments allow mitigating these effects. Therefore, for PVC profile's extrusion, AISI 1035 is acceptable under the specific working conditions analyzed, along with surface protection and maintenance practices, although stainless steels would offer a greater safety margin in corrosive environments.

Key physical properties, such as density and melting point, are crucial for applications involving high temperatures. Thermal conductivity indicates that AISI 1035 steel can effectively dissipate heat, which is beneficial in applications where thermal management is essential (Roque-Villalonga & Camaraza-Medina, 2023).

The higher nickel and chromium content of W.1.2738 steel compared to AISI 1035 significantly improves its hardenability, hardness, and wear resistance, which is especially relevant for the mandrel, as it is subjected to direct contact with molten plastic and higher thermal gradients. These alloys promote greater dimensional stability in the typical extrusion temperature range, reducing deformations due to uneven expansion and stress concentrations during service. For the mandrel, the Ni and Cr combination represents an advantage over a medium-carbon steel like 1035 while, for the adapter and die, which work under lower thermal stress and without direct contact with the molten polymer, AISI 1035 steel offers an adequate compromise between mechanical strength and cost.

3.2.2. Substitute materials evaluation

Stainless steel AISI 304 stands out for its chemical resistance, especially for plastics that do not release corrosive compounds, and its ability to operate at temperatures above 150 °C, thus increasing durability and ease of maintenance (Tang, 2024). However, cost is a factor to weigh against carbon steel with surface treatments, which, although more economical, carries oxidation risks if it is not properly protected (Saengow *et al.,* 2015).

Based on the identification of W.1.2738 for the mandrel and AISI 1035 for the adapter and die, a qualitative evaluation was carried out against other steels commonly used in molds and tools for extrusion and injection, for instance AISI H13, P20, and stainless steels. This comparison considered key physical-chemical properties (wear resistance, thermal stability, and corrosion resistance), as well as aspects related to cost, availability in the Cuban context, and ease of machining.

Steels like H13 exhibit superior strength and high hot hardness, making them suitable for dies subjected to intense thermal cycles, but their cost and greater machining complexity can be inconvenient for PVC extrusion applications with moderate thermal load. Solano Celleri (2025) estimates a cost of 1625.40 USD for extraction dies.

P20 steel and its variants (including P20Ni, equivalent to W.1.2738) offer a favorable concession between mechanical strength, hardenability, dimensional stability, and machinability, which is why they are widely used in plastic molds and are consistent with the material identified in the mandrel.

On the other hand, stainless steels like AISI 304 provide very high corrosion resistance and good performance with non-corrosive plastics, but their higher cost and lower machinability, along with limited availability in the Cuban industrial environment, make them less attractive as a general solution for all nozzle components. In contrast, AISI 1035 steel, used in the adapter and die, offers an adequate balance between strength, toughness, and machinability at a reduced cost, which is particularly relevant for parts that are not in direct contact with the molten polymer and operate under lower thermal gradients.

The characterization results and qualitative comparison against other candidate steels support the validation of W.1.2738 steel as the ideal material for the mandrel and AISI 1035 steel for the adapter and die. Furthermore, they allow proposing substitute materials for scenarios with higher service demands or different corrosion and wear conditions.

3.3. Proposed methodology

The applied proposal was organized into successive stages integrating reverse engineering, service analysis, and bibliographic and standards verification. This methodological sequence offers guidance from the characterization of the available nozzle and the chemical composition determination to steels identification according to DIN/AISI standards, properties, costs, and availability evaluation, and the final selection of materials and potential substitutes for each component. The proposed methodology not only structures the applied process, but also offers a replicable scheme for other industrial applications where selecting extrusion nozzle materials is required for an equipment without detailed information from the original manufacturer.

Selecting the appropriate material for each nozzle component optimizes extruder efficiency, improves final product quality, and reduces costs associated with maintenance and premature replacement. The ability to adapt the nozzle material to the specific process conditions and the type of polymer to be extruded translates into a significant competitive advantage (Patrick, 2002).

This reported research facilitates the material selection process for the three parts forming the extrusion nozzle. Using the reverse engineering method ensures the reliability of the process, while the substitute materials proposal broadens the selection spectrum based on cost-benefit criteria.

This study provides an attractive methodology that guarantees manufacturing nozzles with a high degree of safety, especially when original manufacture specifications are missing or when seeking to optimize existing designs.

4. Conclusions

A material selection procedure to manufacture nozzles for the plastic hose extrusion process at Ernesto Che Guevara Industrial Company was formulated and applied. It integrates reverse engineering, chemical analysis by optical emission spectrometry, and correlation with DIN and AISI standards.

Based on the chemical composition obtained and the bibliographic and normative information, W.1.2738 steel was identified as the suitable material for the mandrel, due to its combination of wear resistance, thermal stability, and machinability under typical plastic extrusion conditions.

The adapter and die were identified as components manufactured in AISI 1035 steel, whose moderate mechanical properties, good machinability, and satisfactory performance after more than 20 years of service support it as an appropriate option for these structural elements of the nozzle.

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Author's Contribution according to CRediT Taxonomy

Isabel X. García Rodríguez: Conceptualization/Methodology/Writing – original draft
Julio Cesar Olangua García: Formal analysis/Methodology/Investigation
Manuel Cantos Macías: Validation/Conceptualization/Writing – review & editing