Espirales
Revista multidisciplinaria de investigación científica

Elasticity and plasticity of PLA, PETG, ABS polymers for printing automotive parts

Elasticidad y plasticidad de los polímeros PLA, PETG y ABS para la impresión de piezas de automoción

Daniela Estefanía Cuenca Pérez*
Ember Geovanny Zumba Novay*
Holger Patricio Castillo Mazón*
Jean Pierre Quinchuela Llamuca*

Received: May 18, 2024
Approved: September 28, 2024

Cuenca, D., Zumba, E., Castillo, H., Quinchuela, J. (2024) Elasticity and plasticity of pla, petg, abs polymers for printing automotive parts. *Espirales Revista Multidisciplinaria de investigación científica*, *8* (51), 51- 66

* Ingeniera Química, Alicante, España. Docente Escuela Superior Politécnica de Chimborazo – ESPOCH, aleinad_cuenca@hotmail.com, https://orcid.org/0009-0008-9446-8187

* Magister en Diseño Industrial y de Procesos - Magister en Educación Tecnología e Innovación, Docente Escuela Superior Politécnica de Chimborazo – ESPOCH, Riobamba, Ecuador. ezumba@espoch.edu.ec, https://orcid.org/0000-0002-2121-8418

* Magister en Pedagogía del Inglés como Lengua Extranjera, Docente Escuela Superior Politécnica de Chimborazo – ESPOCH, Riobamba, Ecuador. holger.castillo@espoch.edu.ec, https://orcid.org/0000-0002-6853-6341

* Ingeniero Mecánico. Ingeniero en Refrigeración Industrial, Docente Escuela Superior Politécnica de Chimborazo – ESPOCH, Riobamba, Ecuador, jean.quinchuela@epn.edu.ec https://orcid.org/0009-0001-9222-3484

Abstract

The objective of this paper is to explore the elasticity and plasticity properties of PLA, PETG and ABS polymers in the context of 3D printing of automotive parts. The present research is qualitative, descriptive, focusing on the theoretical analysis of the mechanical properties of PLA, PETG and ABS polymers, which is based on the collection of information from different authors. An analysis of the properties of these polymers is very significant for their application in the automotive industry, allowing a correct selection of materials. The research found very important data, highlighting that PLA, with its high stiffness and low plasticity, is ideal for prototypes and low-stress parts, while PETG offers a balance between flexibility and strength, suitable for functional components that require durability. ABS, known for its high impact strength and ductility, is recommended for applications that demand shock absorption and durability under demanding conditions. Selecting the right material is crucial to optimize the performance and longevity of 3D printed automotive parts, contributing to the advancement of additive manufacturing technology in the industry.

Keywords: Elasticity, Plasticity, 3D Printing, Automotive parts.

Resumen

El objetivo de este trabajo es explorar las propiedades de elasticidad y plasticidad de los polímeros PLA, PETG y ABS en el contexto de la impresión 3D de piezas de automoción. La presente investigación es cualitativa, descriptiva, centrada en el análisis teórico de las propiedades mecánicas de los polímeros PLA, PETG y ABS, que se basa en la recopilación de información de diferentes autores. El análisis de las propiedades de estos polímeros es muy significativo para su aplicación en la industria automovilística, permitiendo una correcta selección de los materiales. La investigación encontró datos muy importantes, destacando que el PLA, con su alta rigidez y baja plasticidad, es ideal para prototipos y piezas de bajo estrés, mientras que el PETG ofrece un equilibrio entre flexibilidad y resistencia, adecuado para componentes funcionales que requieren durabilidad. El ABS, conocido por su gran resistencia al impacto y ductilidad, se recomienda para aplicaciones que exigen absorción de impactos y durabilidad en condiciones exigentes. Seleccionar el material adecuado es crucial para optimizar el rendimiento y la longevidad de las piezas de automoción impresas en 3D, contribuyendo al avance de la tecnología de fabricación aditiva en la industria.

Palabras clave: Elasticidad, Plasticidad, Impresión 3D, Piezas de automoción.

Introduction

The word polymer literally means "many parts". In this sense, a solid polymeric material can be considered one that contains multiple chemically linked parts or units that are joined together to form a solid. Plastics are divided into two classes, thermoplastics and thermosets. (Hashemi, 2006)

According to studies carried out by Callister (2014) polymers include the well-known plastic and rubber materials. Many of them are organic compounds chemically based on carbon, hydrogen and other non-metallic elements. They have very large molecular structures, often in the form of a chain, which usually have a backbone of carbon atoms.

While Askeland (2016) considers thermoplastics to be a special group of polymers in which the molecular chains are entangled, but not interconnected. They can be easily melted and formed into useful shapes. Generally, these polymers have a structure like that of a chain.

A wide range of thermoplastic filaments such as PLA, ABS, and PETG are used in 3D printing. Disposing of these in landfills or burning them is an ill-advised idea as they have negative repercussions on the environment. Processing the materials before they can be reused also requires energy and this adds to the impact that the respective materials have on the environment. Therefore, the choice of filament type plays an important role in the circular economy of filaments. Kumar (2022).

Materials and methods

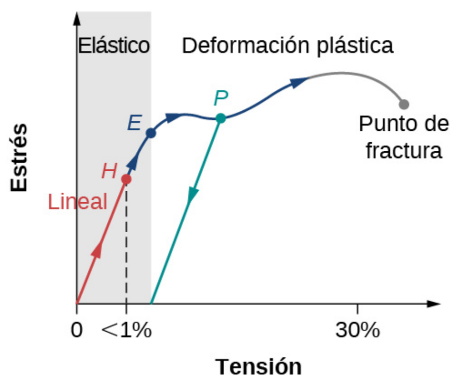
A literature study was conducted on the mechanical properties of PLA, PETG and ABS polymers. The values of tensile strength, modulus of elasticity and elongation at break of each material were investigated. Concepts of 3D printing, elasticity and plasticity were reviewed using official sources obtained from the library of the Faculty of Mechanics as well as digital sources such as Google Scholar, Scopus and Microsoft Academic. Having reviewed 30 articles, 1 documentary, 5 books, 14 videos which contained information in accordance with the present research, 3 books and 30 articles were selected.

In classical mechanics, "plasticity" describes the deformation induced by an external stress that remains permanent after the stress is removed. "Elasticity" describes the fdeformation that is reversed when the stress is released. Therefore, plasticity and elasticity refer to clearly different stress response behaviors of the material. Colombi (2024).

The two parameters that determine the elasticity of a material are its elastic modulus and its yield strength. A high elastic modulus is typical of materials that are difficult to deform; that is, materials that require a high load to achieve significant tension. An example is a steel strip. A low elastic modulus is typical of materials that deform easily under load; for example, a rubber band Mechatronics (2020).

Each material has its own characteristic stress-strain curve.

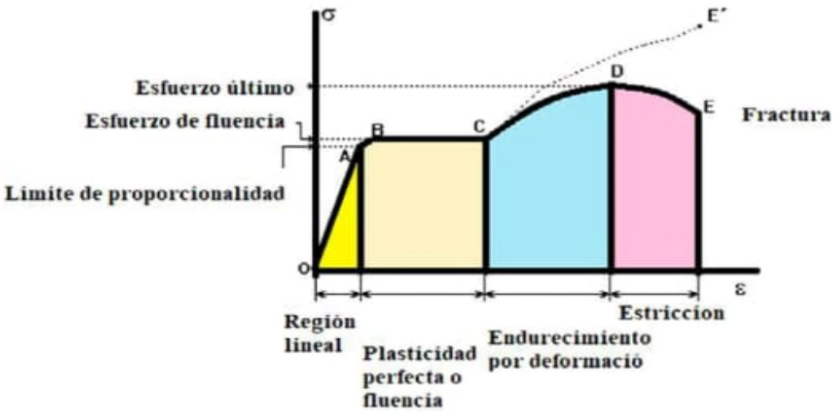
Figure 1. Stress-Tension Diagram



Source: Mechatronics (2020)

A typical stress-strain diagram for a ductile metal subjected to a load. In this figure, the stress is a fractional elongation (not drawn to scale). As the load is gradually increased, the linear behavior (red line) that begins at the unloaded point (the origin) ends at the limit of linearity at point H. For further load increments beyond point H, the stress-strain relationship is nonlinear, although still elastic. In the figure, this nonlinear region is seen between points H and E. Increasingly increasing loads drive the stress to the yield point E, where elastic behavior ends and plastic deformation begins. Beyond the yield point, when the load is removed, for example at P, the material relaxes to a new shape and size along the green line. That is, the material is permanently deformed and does not return to its initial shape and size when the stress is removed. Jesus, (2018).

Figure 2. Stress and strain diagram



Source: Zumba (2024)

Importance in 3D Printing

In 3D printing, especially for automotive applications, elasticity and plasticity properties are crucial for several reasons: Antolín, (2012)

Elasticity in Automotive Parts.

Shock Absorption: Components that may suffer impacts or vibrations (such as engine mounts) need elastic materials that can absorb and dissipate energy, reducing damage to other parts. Askeland, (2016)

Shape Recovery: Parts such as gaskets and seals need to recover their original shape after deformation to ensure proper sealing and continued operation. Jesus, (2018)

Plasticity in Automotive Parts.

Formability: Some components require forming or adjusting after printing. The ability of a material to be molded without fracturing is essential. Askeland, (2016)

Resistance to Permanent Deformations: In situations where parts are subject to continuous loads or high temperatures, high plasticity ensures that parts do not fracture under extreme stress, maintaining structural integrity. Romero, (2023).

Examples of Applications in Automotive 3D Printing:

Brackets and Mounts: They need elasticity to absorb vibrations and shocks without breaking. Kumar, (2022)

Interior Components: Plastics with good plasticity to mold complex shapes and fit the interior contours of the car. Callister, (2014)

Prototypes and Custom Parts: The ability to adjust 3D printed parts for a perfect fit is vital, requiring both elasticity and plasticity. Askeland, (2016)

The right combination of elasticity and plasticity in 3D printed materials is essential to ensure parts function properly under the dynamic and varied conditions found in automotive applications. Antolín, (2012)

Analysis of PLA (Polylactic Acid)

Figure 3. PLA

Source: Antolin Group.

Elasticity and Plasticity of PLA

Elasticity

Behavior under stress: PLA has limited elasticity and tends to be more brittle compared to other polymers. Its elastic modulus is relatively high, meaning it is stiff and does not deform easily under moderate stresses. Kumar, (2022)

Recovery: It does not recover well from plastic deformations, as it tends to break rather than permanently deform. Rodriguez, (2023).

Plasticity:

Permanent deformation: PLA has low plasticity. Once its elastic limit is exceeded, it is more prone to fracture than to permanently deform. Callister, (2014)

Ductility: PLA's ductility is limited, making it less suitable for applications that require considerable deformation without fracture. Rodriguez, (2023).

Advantages and Limitations of PLA in Automotive Applications

Advantages:

Biodegradability: PLA is biodegradable and compostable under industrial conditions, which is a significant environmental benefit. Kumar, (2014).

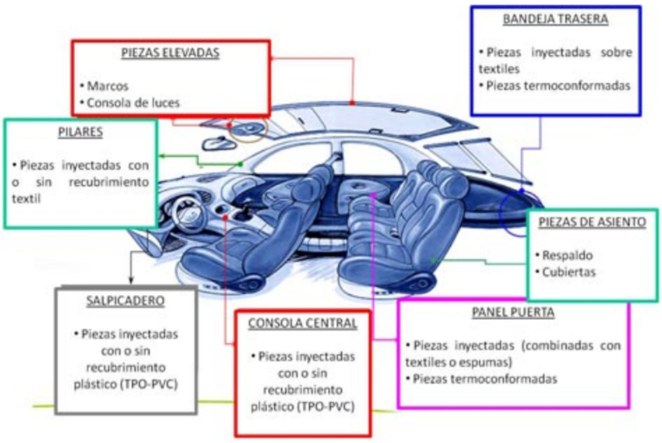
Ease of printing: It prints well at low temperatures and does not require a heated bed, reducing the cost and complexity of printing. Antolín, (2022).

Limitations:

Thermal resistance: PLA has a low thermal resistance (up to about 60°C), which limits its use in components exposed to high temperatures. Rodríguez, (2023).

Fragility: Its low elasticity and plasticity make it more prone to fracture under mechanical loads and shocks, limiting its use in structural parts or those subjected to significant stresses. Rodríguez, (2023).

Figure 4. Auto parts



Source: Antolin Group.

Figure 5. PETG

Analysis of PETG (Polyethylene Terephthalate Glycol)

Source: Antolin Group.

Elasticity and Plasticity of PETG

Elasticity:

Behavior under stress: PETG has good elasticity, allowing it to withstand moderate deformations and recover its original shape without fracturing. Hasemi, (2006).

Recovery: It has excellent elastic recovery, making it suitable for applications requiring flexibility. Hasemi, (2006).

Plasticity:

Permanent deformation: PETG can be plastically deformed without breaking, which gives it good ductility. Hasemi, (2006).

Ductility: It is more ductile than PLA, allowing greater deformation before reaching the fracture point. Rodríguez, (2023).

Advantages and Limitations of PETG in Automotive Applications

Advantages

Impact resistance: It has a high impact resistance, making it ideal for parts that require durability. Bozzelli, (2021).

Thermal stability: It has better thermal resistance than PLA (up to about 75-80°C), allowing it to be used in more demanding environments. Rodríguez, (2023).

Chemical resistance: It offers good resistance to acids and alkalis, which is beneficial in automotive applications. Antolín, (2022).

Limitations

Biodegradability: It is not biodegradable like PLA, which can be a disadvantage from an environmental point of view. Kumar, (2022)

Cost: It can be more expensive than PLA, which can be a limiting factor in low-cost applications. Rodríguez, (2023).

Figure 6. Gears

Source: Antolin Group

Analysis of ABS (Acrylonitrile Butadiene Styrene)

Elasticity and Plasticity of ABS

Figure 7. ABS

Source: Antolin Group.

Elasticity

Behavior under stress: ABS has good elasticity and can absorb shocks and vibrations without fracturing. Bozzelli, (2021).

Recovery: It recovers its shape well after elastic deformations, making it suitable for applications requiring resilience. Bozzelli, (2021).

Plasticity

Permanent deformation: ABS has high plasticity, allowing significant permanent deformations before fracturing. Antolín, (2022).

Ductility: It is highly ductile, allowing it to be molded and adjusted without risk of breakage. Kumar, (2022) Advantages and Limitations of ABS in Automotive Applications

Advantages

Durability: It is extremely durable and impact resistant, making it ideal for structural parts and parts exposed to mechanical stress. Bozzelli, (2021).

Chemical resistance: It offers good resistance to many chemicals, which is crucial in automotive applications. Antolín, (2022).

Thermal resistance: It has a high thermal resistance (up to about 100°C), allowing its use in applications involving heat. Kumar, (2022)

Limitations

Environmental impact: It is not biodegradable and its production and disposal have a greater environmental impact. Rodríguez, (2023).

Vapor emissions: During printing, it emits strong and potentially toxic vapors, requiring adequate ventilation and safety measures Bozzelli, (2021).

Figure 8. ABS printed part

Source: Antolin Group.

Results

In a recent study, conducted by Bozzelli (2021), the elasticity and plasticity properties of PLA, PETG, and ABS polymers were evaluated in the context of their use in 3D printing of automotive parts. These materials were analyzed to determine their suitability in applications requiring high precision, mechanical strength, and the ability to absorb impacts. Key results of the study are presented below.

The plasticity of PLA showed an average Young's modulus of 3.5 GPa, indicating a relatively high stiffness. This means that the material has a limited ability to deform elastically under load, recovering its original shape when the stress is removed. In automotive applications, this property makes PLA more suitable for components that are not subject to repetitive mechanical stress. Plasticity The plastic deformation limit of PLA was approximately 2.5%, with a tensile strength of 60 MPa. This indicates that PLA

is susceptible to fracturing under high stresses, limiting its use in parts that require impact absorption or significant plastic deformations. Antolín, (2022). While in the Mechanical properties of PETG, elasticity: PETG presented a Young's modulus of 2.2 GPa, making it more flexible than PLA. This moderate elasticity allows PETG to absorb deformations without fracturing, which is beneficial for automotive applications where flexibility and energy absorption are critical, such as in interior assembly components. Plasticity PETG's ability to withstand plastic deformations was notably superior, with an elongation at break of 25%. The tensile strength reached 50 MPa, demonstrating a good combination of ductility and strength. This makes PETG suitable for parts that require a balance between rigidity and flexibility. Kumar, (2022). Mechanical properties of ABS Plasticity ABS exhibited a Young's modulus of 2.8 GPa, falling between PLA and PETG in terms of stiffness. However, its higher toughness makes it less prone to fracture under shock loads, a valuable feature for automotive applications involving exposure to dynamic forces. Therefore, plasticity ABS showed an elongation at break of 40%, standing out as the most ductile of the three materials. The tensile strength was 45 MPa. These properties make ABS ideal for automotive components subject to impact, vibration, and thermal fluctuations, such as instrument housings and assembly components. Antolín, (2022).

Table 1. *Materials comparison table*

Characteristic	PLA(Polylactic Acid)	PETG (Polyethylene Terephthalate Glycolate)	ABS (Acrylonitrile Butadiene Styrene)
Density [g cc-1]	1.3	1.27	1.1
Thermal resistance	180-220 °C	230-250 °C	220-250 °C
Ease of printing	High (less deformation problems and good adhesion)	Medium (good adhesion, but may require adjustment)	Media (more warping issues, requires heated bed)
Impact resistence	3.5 GPa	2.2 GPa	2.8 GPa
Elastic modulus stress (GPa)	3.5	2.02	2.3
Flexural strength	80	68	80
Finish	Smooth and shiny surface	Smooth and shiny surface	Matte surface and can be sanded and painted

Conclusions

The study of the elasticity and plasticity properties of PLA, PETG and ABS polymers has revealed distinctive characteristics that significantly influence their suitability for 3D printing of automotive parts. Each of these materials offers a unique set of mechanical properties that can be leveraged in different applications within the automotive industry. Proper material selection is crucial to ensure the functionality, durability and safety of the parts produced. Madias (2003)

For Carmiña (2018) in her research she mentions that PLA, known for its rigidity and ease of printing, stands out in applications where precision and dimensional stability are a priority. However, its low shock absorption capacity and limited plasticity make it less suitable for components subjected to dynamic loads or high temperatures. This restricts its use mainly to the creation of prototypes, aesthetic models and parts that are not subjected to great mechanical stress. On the other hand, PETG offers intermediate flexibility and good impact resistance, making it ideal for parts that require a balance between rigidity and ductility. Its ability to withstand deformations without fracturing is especially valuable in components that need to resist mechanical stresses and varying environmental conditions. These characteristics position PETG as a versatile option for a variety of automotive applications, including supports and interior structural elements.

On the contrary, MexPolímeros (2024), highlights that ABS stands out for its high impact resistance and remarkable plasticity, essential characteristics for parts that must withstand shocks and vibrations. Its ductility allows parts to absorb energy without fracturing, which is crucial in safety and durability applications. This combination of mechanical properties makes ABS the preferred choice for critical components such as instrument housings and exterior parts that must face demanding conditions.

According to research carried out by Ember Zumba, in the articles "Optimization of the manufacturing process by 3D printing of the glass lift handle in Chevrolet Aveo Family" Zumba (2021) and "Alternative Material for the plastic injection molding of the Kia Rio´s ventilation grille" (Merizalde-Salas et al., 2023) it was found that PLA is a biodegradable material that has excellent mechanical, physical and thermal conditions.

References

Antolin, G. (12 de 11 de 2012). Interempresas. Obtenido de https://www.interempresas.net/Plastico/Articulos/103477-Fabricacion-de-piezas-para-el-interior-del-automovil.html

Askeland, D. R. (2016). Ciencia e ingeniería de materiales. Santa Fe: Cengage Learning.

Alfonso, V. B. C., & Mecatrónica. (2020a, febrero 28). Caracterización de las propiedades mecánicas de materiales impresos mediante la técnica de impresión 3D fused deposition modeling (FDM). https://repositorio.utn.edu.ec/handle/123456789/10301

Ana, V. M., De València Departamento de Ingeniería Mecánica y de Materiales - Departament D'Enginyeria Mecánica I de Materials, U. P., & De València Escuela Técnica Superior de Ingeniería del Diseño - Escola Técnica Superior D'Enginyeria del Disseny, U. P. (2023, 26 septiembre). Diseño y cálculo de una prótesis transradial infantil mediante el análisis por elementos finitos. https://riunet.upv.es/handle/10251/197035

Bozzelli, J. (2021, 20 mayo). Cómo lidiar con el estrés residual en piezas moldeadas. Gardner Business Media, Inc. https://www.pt-mexico.com/columnas/como-lidiar-con-el-estres-residual-en-piezas-moldeadas

Colombi, T. (2024). Root plasticity versus elasticity. CellPress.

Callister, W. D. (2014). Materials Science and Engineering. United States Of America: Wiley Binder.

COMERCIAL ANDEXPORT. https://andexport.com/producto/equipo-para-ensayos-de-traccion/

Carmiña, G. V. (2024). Evaluación de las propiedades de mezclas binarias de polímeros mixtos posconsumo con polipropileno reciclado. https://bibliotecadigital.udea.edu.co/handle/10495/39882

De Tecnología del Plástico, T. R. P. (2023, 7 julio). Plásticos ara impresión 3D, guía definitiva. Plástico. https://www.plastico.com/es/noticias/plasticos-para-impresion-3d-guia-definitiva

Equipo de ensayo de tracción y estiramiento - Industrial Physics. (2023, 31 octubre). Industrial Physics. https://industrialphysics.com/es/base-de-conocimientos/articulos/equipo-de-ensayo-de-traccion-y-estiramiento/

Equipo para ensayos de tracción XLW (PC) - COMERCIAL ANDEXPORT. (s. f.).

Estrés versus tensión en foco: diferencias clave e ingeniería. (2020). https://www.tuofa-cncmachining.com/es/tuofa-blog/stress-vs-strain.html

Hashemi, W. F. (2006). Fundamentos de la ciencia e ingeniería de materiales. México: The McGraw-Hill Companies.

Jesus. (2018, 10 abril). Lo que nadie te ha contado sobre imprimir en PETG. Todo-3d.com. https://todo-3d.com/todo-sobre-imprimir-en-petg/?v=911e8753d716

Kumar, R. (2022). A comparative Study on the Life Cycle Assessment of a 3D Printed Product With PLA, ABS & PETG Materials. India: Elsevier.

Krear 3D. (2021, 16 marzo). La configuración perfecta para imprimir con PETG. Krear 3D. https://tiendakrear3d.com/consejos/la-configuracion-perfecta-para-imprimir-con-petg/

Libretexts. (2022, 2 noviembre). 4.7: Relaciones Estrés-Tensión. LibreTexts Español. https://espanol.libretexts.org/Quimica/Qu%C3%ADmica_Org%C3%A1nica/Libro%3A_Qu%C3%ADmica_de_Pol%C3%ADmeros_%28Schaller%29/04%3A_Propied ades_del_Pol%C3%ADmero/4.07%3A_Relaciones_Estr%C3%A9s-Tensi%C3%B3n

PETG | PRUSA Knowledge Base. (2019). https://help.prusa3d.com/es/article/petg_2059

M, A., & M, A. (2021, 11 mayo). PLA vs PETG: ¿Qué material de impresión 3D elegir? 3Dnatives. https://www.3dnatives.com/es/pla-vs-petg-material-elegir-110520212/

Mexpolimeros. (2020). Elasticidad. Polímeros Termoplásticos, Elastómeros y Aditivos. https://www.mexpolimeros.com/etp/elasticidad.html

Merizalde-Salas, A., Zumba-Novay, E., & Peralta-Zurita, D. B. (2023). Alternative Material for the plastic injection molding of the Kia Rio's ventilation grille. Revista Científica Interdisciplinaria Investigación y Saberes, 13(1), 1390–8146. http://revistasdigitales.utelvt.edu.ec/revista/index.php/investigacion_y_saberes/article/view/197/249

Millholland, C. D., & Millholland, C. D. (2020, 9 diciembre). Estudiando las propiedades de viscoelasticidad de polímeros y plásticos. Ciencia Acelerada. https://www.thermofisher.com/blog/cienciaacelerada/materiales/polimero-plasticos/estudiando-las-propiedades-de-viscoelasticidad-de-polimeros-y-plasticos/

Módulo elástico y coeficiente de Poisson de materiales poliméricos. (2021). https://www.sonelastic.com/es/fundamentos/tablas-propiedades-materiales/polimeros.html

Moebs, W., Ling, S. J., & Sanny, J. (2021, 28 septiembre). 12.4 Elasticidad y plasticidad - Física universitaria volumen 1 | OpenStax. https://openstax.org/books/f%C3%ADsic a-universitaria-volumen-1/pages/12-4-elasticidad-y-plasticidad

Nth, G. (2021, 6 julio). Cómo imprimir PETG con éxito. Grilon3. https://grilon3.com.ar/como-imprimir-petg-con-exito/

Nth, G. (2022, 2 febrero). PLA vs PETG ¿Cuál te conviene? Grilon3. https://grilon3.com.ar/pla-vs-petg-cual-te-conviene/

Rodríguez, A. (2023, 24 agosto). Máquina de ensayos de tracción - Servosis. Servosis. https://www.servosis.com/maquinas-de-ensayo-de-traccion/

Romero, J. (2023, 19 julio). Materiales de impresión 3D: los termoplásticos más usados. Sicnova. https://sicnova3d.com/blog/experiencias-3d/materiales-de-impresion-3d-los-termoplasticos-mas-usados/

Sierra Sánchez, J., Liberal Ormaechea, S., & Luceno Ramos, B. (2018). Analysis of the subject Final Degree Project (FDP) in Spanish Communication Sciences degrees. Revista Espanola de Documentacion Cientifica, 41(4).

Sierra Sánchez, J., & Sotelo González, J. (2010). Métodos de innovación docente aplicados a los estudios de Ciencias de la Comunicación. Fragua.

S, S. &. (12 de Septiembre de 2023). Los plásticos en la impresión 3D.

S, S., & S, S. (2023, 12 septiembre). Guía completa: Los plásticos en la impresión 3D. 3Dnatives. https://www.3dnatives.com/es/plasticos-impresion-3d-22072015/

Smart Materials 3D. (2021). Filamento PLA para impresión 3D. https://www.smartmaterials3d.com/pla

Tensión y deformación verdadera: conceptos, ejemplos | StudySmarter. (s. f.). StudySmarter ES. https://www.studysmarter.es/resumenes/ingenieria/ingenieria-de-materiales/tension-y-deformacion-verdadera/

Test, I. (2019). Equipos de ensayo de tracción | IDM Test. https://www.idmtest.com/productos/traccion

Zumba, I. E. (2024). INTRODUCCION A LA INGENIERIA DE MATERIALES METÁLICOS ZUMBA ESPOCH 2024.

Zumba Novay, E. G. (2021). Optimización en el proceso de fabricación por impresión 3d de la manija del elevador de vidrios del vehículo Chevrolet Aveo Family para la mejora de propiedades mecánicas y térmicas. http://localhost:8080/xmlui/handle/123456789/407