Articles

Comparison of Properties (stress, resistance and deformation) between low and high carbon steel

Comparación de propiedades (tensión, resistencia y deformación) entre acero con bajo y alto contenido en carbono

Ember Geovanny Zumba Novay*
Carlos José Santillan Mariño*
Daniela Estefanía Cuenca Pérez*
Joan David Espinoza Gallo*

ABSTRACT

The objective of this study is to perform a detailed comparison of the stress, strength and deformation properties between high and low carbon steels to determine their mechanical behavior in different applications. The research is qualitative, descriptive, focusing on the theoretical analysis of the mechanical properties of steel, which is based on the compilation of information from different authors. The differences in the microstructure and mechanical properties of the two steels were analyzed. A comparison of the mechanical properties of low carbon steel and high carbon steel provides valuable information for application in various

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

*Máster en Ciencias Mención Diseño Mecánico, Magíster en Docencia Universitaria e Investigación Educativa, Ingeniero Mecánico, Docente de la Escuela Politécnica de Chimborazo ESPOCH, Riobamba, Ecuador csantillan_m@espoch.edu.ec, https://orcid.org/0000-0002-7167-7452

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

*Estudiante de Ingenieria Mecánica de la Escuela Politécnica de Chimborazo ESPOCH, Riobamba, Ecuador joan.espinoza@espoch.edu.ec, https://orcid.org/0009-0008-9138-0964

REVISTA TECNOLÓGICA
ciencia y educación
Edwards Deming

ISSN: 2600-5867

Edited by: Tecnológico Superior Corporativo Edwards Deming
January - March Vol. 9 - 1 - 2025
https://revista-edwardsdeming.com/index.php/es
e-ISSN: 2576-0971
Received: june 29, 2024
Approved: October 20, 2024
Page 1-17

industrial processes, allowing the selection of the most suitable type of steel according to specific strength and deformation requirements. The research found that the carbon content significantly affects the microstructure of the steel and, consequently, the mechanical properties. Compared with high carbon steel, low carbon steel has lower strength and deformation. High carbon steel has greater strength, but is also more prone to warping under certain loads.
Keywords: steel, composition, carbon, properties, material

RESUMEN
El objetivo de este estudio es realizar una comparación detallada de las propiedades de tensión, resistencia y deformación entre aceros de alto y bajo carbono para determinar su comportamiento mecánico en diferentes aplicaciones. La investigación es cualitativa, descriptiva, centrada en el análisis teórico de las propiedades mecánicas del acero, que se basa en la recopilación de información de diferentes autores. Se analizaron las diferencias en la microestructura y las propiedades mecánicas de los dos aceros. La comparación de las propiedades mecánicas del acero con bajo contenido en carbono y del acero con alto contenido en carbono proporciona información valiosa para su aplicación en diversos procesos industriales, permitiendo seleccionar el tipo de acero más adecuado en función de los requisitos específicos de resistencia y deformación. La investigación descubrió que el contenido de carbono afecta significativamente a la microestructura del acero y, en consecuencia, a las propiedades mecánicas. En comparación con el acero con alto contenido de carbono, el acero con bajo contenido de carbono tiene menor resistencia y deformación. El acero con alto contenido en carbono tiene mayor resistencia, pero también es más propenso al alabeo bajo determinadas cargas.
Palabras clave: acero, composición, carbono, propiedades, material

Articles
Revista tecnológica ciencia y educación Edwards Deming
ISSN: 2600-5867

INTRODUCTION

Steel is an important material in today's world. This material is used in construction, automotive, infrastructure, manufacturing, and machinery projects, among others, where specific characteristics are needed to determine its effectiveness and efficiency. Archer (1963)

According to Luddey (2013), steel is an alloy of iron (Fe) and carbon (C), elements that are found in abundance in the earth's crust.

To do this, it is essential to state that there are several classifications of types of steel. For example, according to Zumba-Novay (2023), hot-rolled steel bar, cold-rolled steel bar, stainless steel sheet, normalized steel bar, and ferric stainless steel bar. However, depending on the carbon composition, it is classified as low-carbon steel and high-carbon steel, while depending on the carbon percentage, specific properties of the material are determined proportionally. Fukuda (2002)

According to Carrillo (2017), low carbon steel is a type of steel that has a low amount of carbon, which typically represents between 0.05% to 0.3% of the total weight of the steel, while high carbon steel varies between 0.6% to 1.5% of carbon content.

Carbon is a crucial element in determining the microstructure, in this sense, the crystalline structure of low carbon steel and high carbon steel contains different phases due to their difference in composition. Archer (1963)

According to Salas (2012), a microstructural phase is a section that contains a uniform crystalline structure, for metals it is defined as different atomic arrangements in its structure which leads to an affectation in its mechanical properties.

The relationship of the microstructural phases between these two steels is that, due to the amount of carbon they have, they will reach different predominant phases, which will give as a product specific properties to which these two types of steels can reach. Kolenkow (2012)

While for Askeland & Wright (2016) the stress is a measure of the intensity of the internal forces, when there is an applied load, and for this there are different types of mechanical stresses in which there are traction, torsion, buckling, compression and shear. Nisbett (2012)

Although studies such as that of Merizalde-Salas et al., (2022) have evaluated alternative materials to steel, such as bamboo fiber, which, in addition to being environmentally friendly, can replace traditional materials by up to 20%, or the study by Zumba-Novay & Merizalde-Salas (2023) that suggests PLA material as an alternative in industrial production, for Gere (2009) steel in different processes must be coupled to different types of stress, so that it does not reach a deformation, which is an undesirable property of materials, since this would lead to deducing that the material is reaching its maximum resistance to reach breakage.

In his research, Callister (2009) states that deformation is the change in shape as a result of mechanical stress, this factor is calculable by the relationship between the initial length and the final length.

ISSN: 2600-5867

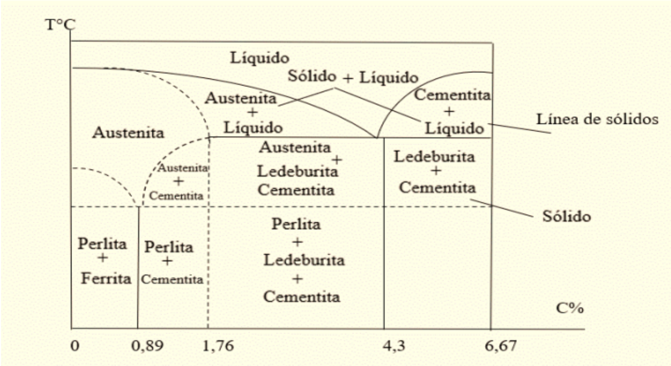
According to Carmo (2012), the deformation that a material can have with respect to stress is crucial in the evaluation of the type of steel to be used, which will determine the resistance factor, to evaluate the maximum stress.
According to Smith (2006), the resistance of a material is the evaluation of the maximum stress that a material can withstand before breaking or reaching a permanent deformation.
The present study aims to make a detailed comparison of the stress, resistance and deformation properties between high and low carbon steels, in order to accurately identify the mechanical behavior of these materials, which can be applied in different processes that involve the use of steel. Mott (2018)

MATERIALS AND METHODS

The type of research carried out is basic, because it contributes to the knowledge regarding mechanical properties, which depends on different factors involved such as the crystalline structure and its microstructural phases. It has a qualitative approach, since the present research is a theoretical reference on this topic that does not involve quantitative data. The research was carried out at a descriptive level but in some aspects at an explanatory level, regarding the basic concepts to understand the subject. Different studies and previous research were reviewed among approximately 60 sources including books, scientific articles and academic works, on high-impact sites such as Google Scholar, Scopus and Microsoft Academic, among which we took around 40 relevant works concerning the subject.
The microstructural phases define specific mechanical properties in each of them. Among these phases we have: Ferrite (α), Pearlite (Fe_3C), Austenite (γ), Martensite. These phases are presented depending on their temperature. (Sriramulu, 1990)
In their research, Fitzgerald & Ordóñez (1996) interpret a phase diagram in which the composition and temperature must be located on the axes, then identify the single phase or equilibrium regions, and use the boundary lines to determine the phases present at those conditions.

Articles
Revista tecnológica ciencia y educación Edwards Deming
ISSN: 2600-5867

Figure 1: Fe-C phase diagram



Source: Zumba (2024)

For Smith (2006) ferrite is a phase that results in soft and ductile steel, cementite is a phase that results in hard and brittle steel, pearlite is a phase that results in strong and hard steel.

In the phase diagram, the different phases can be observed, both in percentage of carbon and in the temperature at which they reach said phase, so it can be deduced that, in the microstructure phase of low carbon steel, ferrite is the dominant phase in low carbon steel, which makes it soft and flexible, which gives the steel. McCormac (2012)

The ability to deform plastically and pearlite, which is composed of ferrite and cementite sheets, pearlite is harder and stronger than pure ferrite, but still retains a certain degree of flexibility. Robots (2006) On the other hand, in the microstructure phase of high carbon steel, the cementite phases predominate, in which the presence of large amounts of cementite (Fe3C) increases the hardness and electrical resistance of the steel and martensite, a phase in which, during cooling, high carbon steel is transformed into martensite, an extremely hard and brittle phase. Ruiz & Blanco (2014)

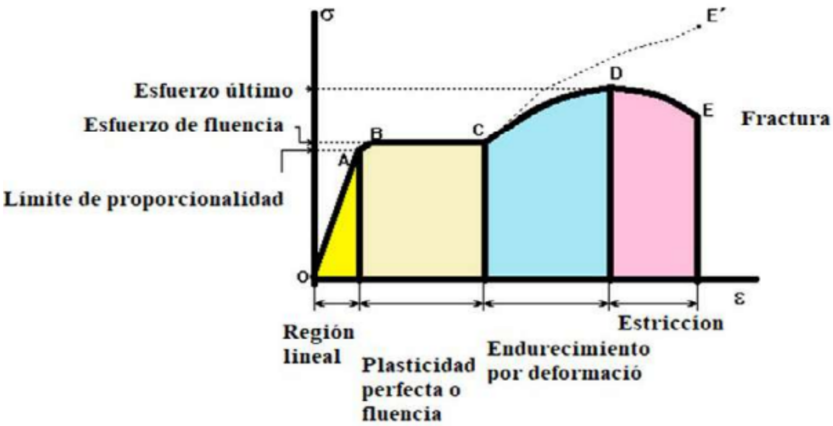
Therefore, low carbon steel has higher ductility and lower strength, exhibiting a longer stress-strain curve before fracture. High carbon steel, on the other hand, has higher strength but lower ductility, with a shorter and steeper stress-strain curve, indicating that it fractures more rapidly under load. Sriramulu (1990). According to Egor & Toader (2000) the tensile strength of high carbon steels is significantly higher due to the formation of martensite or cementite, while low carbon steels, with more ferrite and pearlite, offer greater deformation before breaking.

Articles
Revista tecnológica ciencia y educación Edwards Deming
ISSN: 2600-5867

RESULTS

Below is the stress-strain diagram for low carbon steel:

Figure 2: Stress-strain diagram



Source: Zumba (2024)

In the typical stress-strain curve for low carbon steel we can see that in the initial region, the relationship between stress and strain is linear (Hooke's Law). González (2013)

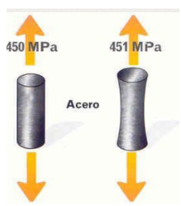
This region is reversible, meaning that the material returns to its original shape when the load is removed. Robots (2006)

In this region the modulus of elasticity (Young's modulus) is constant, the yield point is the point at which the elastic region ends and plastic deformation begins. The stress at this point is known as the yield point; in the plastic region, the relationship between stress and strain is no longer linear. Fitzgerald (1996)

The material undergoes permanent plastic deformation. As the stress increases, the material deforms more easily. After reaching the maximum stress (ultimate stress), the material begins to thin in one area (bottleneck) until it fractures. Shackelford (2005)

The following image details a comparison in tension of these two types of steel.

Figure 3: Tensile stress



Source: Flores & Garamendi (2022)

Articles

Revista tecnológica ciencia y educación Edwards Deming
ISSN: 2600-5867

According to de Heredia (2004) the elastic limit, or yield strength, is the maximum stress that a material can withstand without suffering permanent plastic deformation. For steel, the yield strength varies according to the carbon content and other alloying factors.

In general, low carbon steel has a yield strength typically between 200 and 350 MPa (Megapascals), being more ductile and less resistant than high carbon steel. Güemes (2001)

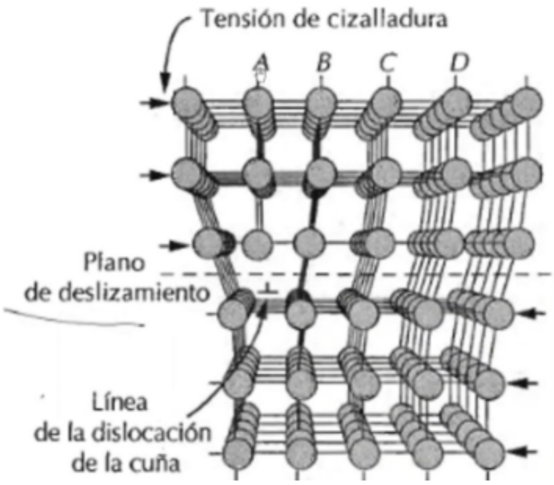
On the other hand, high carbon steel typically has a yield strength of between 500 and 800 MPa, making it stronger and stiffer, but also more brittle. These values are approximate and can vary depending on the exact composition of the steel and the heat treatment it has received. Nisbett (2012)

The difference in plastic deformation between low and high carbon steel is mainly due to their mechanical properties and crystal structure: low carbon steel is more ductile, meaning it can plastically deform faster before fracturing. Carmo (2012)

This is due to its lower carbon content, which gives it a softer structure and allows dislocations to move more easily. Verdeja (1997)

A picture of a dislocation in steel is shown below.

Figure 4: Dislocation in mild steel



Source: Bhadeshia & Honeycombe (2006)

Low carbon steel can be stretched and deformed significantly without fracturing, making it ideal for applications requiring flexibility and shock absorption. On the other hand, high carbon steel is less ductile and harder. Garcia (2002)

Articles

Revista tecnológica ciencia y educación Edwards Deming
ISSN: 2600-5867

Its higher carbon content gives it a stiffer structure and makes it more difficult for dislocations to move, resulting in a lower capacity for plastic deformation. Untener (2018).

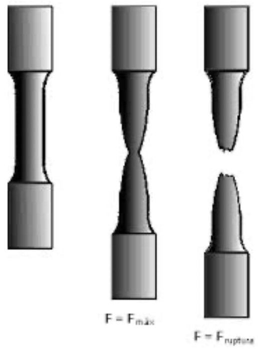
This type of steel tends to be more brittle, meaning it can fracture with less plastic deformation under stress. While it is stronger and more resistant to wear, it is less able to absorb deformations before fracture. González (2013)

The difference in strength between low carbon steel and high carbon steel is manifested in different mechanical properties: low carbon steel has a tensile strength generally between 370 and 700 MPa, being less resistant but more ductile and malleable, allowing it to deform significantly without breaking. Kolenkow (2012)

In contrast, high carbon steel has a tensile strength of between 850 and 1200 MPa, being stronger and tougher due to its higher carbon content, but less ductile and more prone to fracture under extreme stress. Quintero (1974)

A picture of steel tensile strength is presented below:

Figure 5: Bottleneck in steel



Source: Shackelford (2005)

In terms of wear resistance, low carbon steel has lower strength due to its softer structure, while high carbon steel offers greater resistance to wear and abrasion, making it suitable for applications requiring higher surface hardness. Vinnakota (2006)

In terms of resistance to deformation, low carbon steel has lower resistance to permanent deformation under load, but behaves more ductile and can be machined more easily. Pulido (2017)

On the other hand, high carbon steel has greater resistance to deformation due to its higher hardness, but is less malleable. Merritt (1982)

Examples of the use of low and high carbon steel

Articles
Revista tecnológica ciencia y educación Edwards Deming
ISSN: 2600-5867

In the field of civil engineering and construction, low carbon steel is commonly used to reinforce reinforced concrete. For example, in rebar or "reinforcing bars", low carbon steel is preferred for its ductility, which allows for some flexibility before fracturing. Salas (2012)

This is crucial in structures subject to dynamic loads, such as buildings in seismic zones. Below is an image of steel-reinforced concrete González (2013)

Figure 6: Iron-carbon fibers

Source: Sriramulu (1990)

On the other hand, high carbon steel, although less common in structural applications due to its lower ductility, is used in specific components such as suspension bridge cables or in support elements where high tensile strength is required. Larburu (2008)

Figure 7: Suspension bridge

Source: Merritt (1982)

In automotive engineering, low carbon steel is used in the production of body panels due to its ease of stamping and welding, allowing for complex and lightweight designs. The ductility of this steel is important for absorbing energy in impacts. Schafer (2013)

Articles
Revista tecnológica ciencia y educación Edwards Deming
ISSN: 2600-5867

Figure 8: Body panels

Source: Maldonado (1996)

In contrast, high carbon steel is used in drive system components such as axles and gears where high tensile and wear strength is required. These components must withstand high loads and constant friction without deforming. Blanco (2014)

Figure 9: Transmission system

Source: Larburu (2008)

In mechanical engineering and machinery, low carbon steel is chosen for the construction of frames and support structures because of its ease of fabrication and weldability, allowing the creation of large and complex structures. Sriramulu (1990)

Figure 10: Support structure

Source: Heredia (2004)

Articles
Revista tecnológica ciencia y educación Edwards Deming
ISSN: 2600-5867

High carbon steel, on the other hand, is ideal for cutting tools, such as drills and cutters, and for precision molds, where high hardness and wear resistance are essential to maintain precision and efficiency in work. Madias (2003)

Figure 11: Cutting tools

Source: Larburu (2008)

In infrastructure engineering, low carbon steel is used in the production of pipes and tubes for water and gas conduction due to its good weldability and corrosion resistance if properly protected. Shaabani (2024)

Figure 12: Steel pipes

Source: Kleppner & Kolenkow (2012)

Railway rails, made of high carbon steel, are able to withstand wear and heavy loads, which is critical for the safety and durability of the railway system. Maldonado (1996)

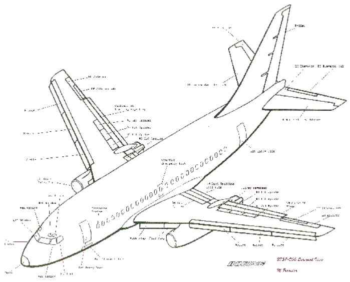
Figure 13: Railway Rails

Source: Maldonado (1996)

Articles
Revista tecnológica ciencia y educación Edwards Deming
ISSN: 2600-5867

In aerospace engineering, low carbon steel is used in non-critical aircraft components, where weight and ease of production are more important than extreme strength. For example, in some parts of the fuselage or in internal supports. McCormac (2012)

Figure 14: Aircraft fuselage



Source: Archer (1963)

In contrast, high carbon steel is used in critical parts such as the landing gear, where high strength and toughness are needed to withstand impact forces during landing. Toader (2000)

Figure 15: Aircraft landing gear

Source: Callister (2009)

In all these examples, the relevance of the difference in the properties of the two types of steel, which directly depend on the amount of carbon, could be established.

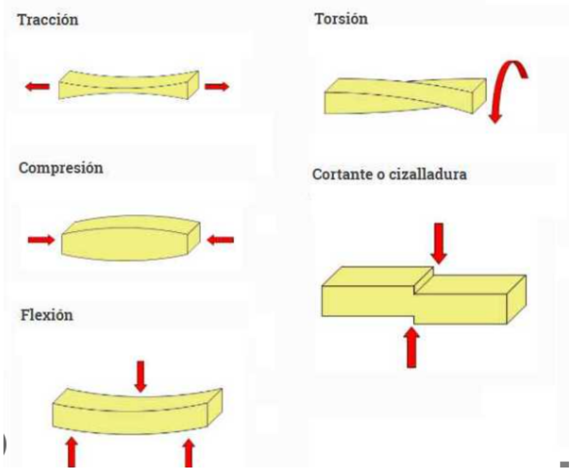
DISCUSSION

Steel is a fundamental material in the modern world, used in a wide range of sectors such as construction, automotive, infrastructure, manufacturing and machinery. Its effectiveness and efficiency depend on its specific characteristics. There are different types of steel depending on the carbon composition: low carbon steel and high carbon steel. Verdeja (1997)

Steels are involved with punctual stresses throughout their useful life, therefore, it is necessary to understand mechanical stresses.

Articles
Revista tecnológica ciencia y educación Edwards Deming
ISSN: 2600-5867

Figure 16: Mechanical stresses



Source: Mott (2018)

In his research, Merritt (1982) states that traction is an axial stress that occurs when a material is subjected to opposing forces that act along its longitudinal axis, generating an elongation in the material. In the case of low carbon steel, it has lower tensile strength, but is more ductile and easier to form. On the other hand, high carbon steel has greater tensile strength and hardness, but is less ductile.

In terms of compression, for Caicedo et al., (2024), it is the axial stress that occurs when a material is subjected to opposing forces that act along its longitudinal axis, generating a reduction in its length. In the context of low carbon steel, it has lower compressive strength, but is more ductile and easier to work. On the other hand, high carbon steel has greater compressive strength and hardness, but is less ductile and more prone to fracture under high loads.

For Hibbeler (2010), torsion is the stress that occurs when a material is subjected to a pair of opposing forces acting along its longitudinal axis, generating a twist or twist in the material, in agreement with the low carbon steel has lower resistance to torsion but is more ductile and easier to work, however, high carbon steel has greater resistance to torsion and hardness, but is less ductile and more prone to fracture under high torsion

While for Orna et al., (2020) shear is the stress that occurs when a material is subjected to opposing forces acting in parallel planes, generating an internal slip between the layers of the material, for low carbon steel it has lower resistance to shear but is more ductile and easier to work, on the other hand, high carbon steel has greater resistance to shear and hardness, but is less ductile and more prone to fracture under high shear forces

Articles
Revista tecnológica ciencia y educación Edwards Deming
ISSN: 2600-5867

According to McCormac (2012), bending is the stress that occurs when a material is subjected to forces that act perpendicular to its longitudinal axis, generating a curvature or bending in the material, for example, low carbon steel has lower bending strength but is more ductile and easier to work, in comparison, high carbon steel has greater bending strength and hardness, but is less ductile and more prone to fracture under high bending loads.

The amount of carbon determines the specific properties of the material. Low carbon steel contains between 0.05% and 0.3% carbon, while high carbon steel ranges from 0.6% to 1.5%. Carbon is essential in determining the microstructure of steel, influencing its mechanical properties. Shaabani (2024)

A microstructural phase is a section with a uniform crystalline structure and the different atomic arrangements in metals affect their mechanical properties. Stress is defined as a measure of the intensity of internal forces when a load is applied, with different types of mechanical stresses such as tension, torsion, buckling, compression and shear. Correa (2007)

Steel must adapt to these stresses to avoid deformations, an undesirable property that indicates that the material is reaching its maximum strength before breaking. Deformation is the change in shape due to a mechanical stress, calculable from the relationship between the initial and final length. Ray (1994)

Strain in relation to stress is essential to evaluate the type of steel to be used and determine its maximum strength. The strength of a material is the maximum stress it can withstand before breaking or permanently deforming. Bohórquez (2012)

This study proposes a detailed comparison of the stress, strength and deformation properties between high and low carbon steels, to accurately identify the mechanical behavior of these materials and their application in various processes that require the use of steel. Garcia (2002)

This detailed comparison of tensile, strength and strain properties between high and low carbon steels will allow for better selection of materials for various industrial applications.

REFERENCES

Aguirre, T. (2021). ESTUDIO MICROESTRUCTURAL DE UN ACERO FUNDIDO ALTO CARBONO-ALTO SILICIO SOMETIDO A TRATAMIENTOS TÉRMICOS DE AUSTEMPERADO Y Q&P.

Alberto, J., & Schafer, A. (2013). Deformación elástica, plástica y fatiga.

Archer, R., Cook. Nathan, & Candall, S. (1963). An Introduction to Mechanics of Solids 2.

Askeland, D. R., & Wright, W. J. (2016). Ciencia e ingeniería de materiales 7ª edición. http://latinoamerica.cengage.com

Bhadeshia, H. K., & Honeycombe, R. (2006). Steels Microstructure and Properties Third Edition.

Bohórquez, C. A., Cardona, A., Kohan, P. H., Quinteros, R. D., & Storti, M. A. (2012). Influencia del Tratamiento Térmico desde Temperaturas Intercríticas en las Propiedades Mecánicas del Acero SAE 1045. Mecánica Computacional, 31(23), 3577–3587. http://venus.ceride.gov.ar/ojs/index.php/mc/article/view/4283

Budynas, R. G., & Keith Nisbett, J. (2012). Diseño en ingeniería mecánica de Shigley, 9na Edición.

Caicedo, I., Buñay, J., Viteri, E., & Pérez, D. (2024). MECÁNICA DE MATERIALES TEORÍA Y EJERCICIOS. http://cimogsys.espoch.edu.ec/direccion-publicaciones/public/docs/books/2021-01-19-155352-Resistencia%20de%20materiales%20final_compressed.pdf

Callister, W. (2009). Ciencia e Ingeniería de los Materiales.

Carmo, D. J., Dias, J. F., & Santos, D. B. (2012). High cycle rotating bending fatigue property in high strength casting steel with carbide free bainite. Https://Doi.Org/10.1179/1743284712Y.0000000047, 28(8), 991–993. https://doi.org/10.1179/1743284712Y.0000000047

Correa, E., Botero, C., & Restrepo, A. (2007). CORROSIÓN DEL ACERO AL CARBONO.

de Heredia, O. (2004). DISEÑO DE ESTRUCTURAS DE ACERO CONSTRUCCIÓN COMPUESTA.

Egor, P., & Toader, B. (2000). Mecánica de Solidos Segunda Edición.

Fitzgerald, R. W., & Ordóñez Reyna, L. (1996). Mecánica de materiales. Alfaomega.

Flores, C., & Garamendi, D. (2022). Comparative Analysis of the strength to compression, flexure and workability of traditional concrete versus a concrete using steel slag as fine aggregate. Artículo de Investigación, 23(1), 20–34. https://doi.org/10.51372/gacetatecnica231.3

Fukuda, Y., Oh-Ishi, K., Horita, Z., & Langdon, T. G. (2002). Processing of a low-carbon steel by equal-channel angular pressing. Acta Materialia, 50(6), 1359–1368. https://doi.org/10.1016/S1359-6454(01)00441-4

Garcia, L. (2002). Decarburación bajo vacío durante el proceso de fabricación de aceros inoxidables austeníticos. https://www.researchgate.net/publication/263531322

Gere, J. M., Goodno, B. J., León Cárdenas, J., & Ponciano Guzmán, jose nicolas. (2009). Mecánica de materiales. Congage Learning.

González, C. (2013). Ingeniería y Ciencia. http://www.redalyc.org/articulo.oa?id=83510105

Güemes, A., Nuria, G., & Piris, M. (2001). Ciencia de materiales para ingenieros. http://fullengineeringbook.blogspot.com

Hibbeler, R. (2010). Ingeniería mecánica - Estática.

Kleppner, D., & Kolenkow, R. J. (2012). An Introduction to Mechanics.

Larburu, N. (2008). Prontuario de Maquinas Nicolás Larburu.

Luddey, J., Burbano, V., & Peláez, J. (2013). Analysis of stainless steel weldability with medium and low carbon by SMAW steel. 22(35), 91–100.
Madias, J., Varela, R., Reggiardo, H., Pagliano, V., & Desarrollo Aceria ASE, M. (2003). Obturacion de buzas de cuchara : caso de aceros de alto carbono calmados a1 silicio-manganeso-aluminio*.
Maldonado, J. (1996). Aceros y sus Aplicaciones.
McCormac, J. C. (2012). Diseño de estructuras de acero. Marcombo.
Merizalde-Salas, A., Zumba-Novay, E., & Belén Peralta-Zurita, D. (2022). Alternative Material for the plastic injection molding of the Kia Rio's ventilation grille Material alternativo para el moldeo por inyección de plástico de la rejilla de ventilación del Kia Rio (Vol. 13, Issue 1). https://orcid.org/0000-0002-0469-5079
Merritt, F. S. (1982). Manual del ingeniero civil. Tomo I, 4ta Edición.
Mott, R., & Untener, J. (2018). Applied Strength of Materials, Sixth Edition SI Units Version.
Orna, J., Caicedo, I., Mayorga, D., & Viteri, E. (2020). Resistencia de materiales. http://cimogsys.espoch.edu.ec/direccion-publicaciones/public/docs/books/2024-05-29-143517-Mec%C3%A1nica%20de%20materiales%20teor%C3%ADa%20y%20ejercicios.pdf
Pulido, C., & Carrillo, J. (2017). Flexural mechanical properties of steel fiber reinforced concrete under corrosive environments Propiedades mecánicas a flexión del concreto reforzado con fibras de acero bajo ambientes corrosivos. www.ricuc.cl
Quintero, A. (1974). CINETICA DE ENVEJECIMIENTO DE ACERO.
Ray, R. K., Jonas, J. J., & Hook, R. E. (1994). Cold rolling and annealing textures in low carbon and extra low carbon steels. International Materials Reviews, 39(4), 129–172. https://doi.org/10.1179/IMR.1994.39.4.129
Robots, P. (2006). Solid Mechanics and its applications.
Ruiz, M. C., & Blanco, E. (2014). Mecánica y Resistencia de Materiales.
Salas-Banuet, G., Jaime, O., Baena, R., Cockrell, B. R., Ramírez-Vieyra, J., & Noguez-Amaya, M. E. (2012). Edicion Especial. 79, 70–96.
Shaabani, A., Jamaati, R., & Hosseinipour, S. J. (2024). Mechanical anisotropic behavior of low-carbon steel processed by asymmetric rolling. Heliyon, 10(13). https://doi.org/10.1016/j.heliyon.2024.e34004
Shackelford, J. F. (2005). Introducción a la ciencia de materiales para ingenieros 6ª edición.
Smith, W. F., Hashemi, J., Nagore, G., Esquivel, R., & Barba, A. (2006). Fundamentos de la ciencia e ingeniería de materiales.
Sriramulu, V. (1990). Estructuras de Acero Comportamiento y LRFD.
Verdeja, L. F., Alfonso, ; A, & Huerta, A. (1997). Aplicación del diagrama Fe-C estable al cálculo de parámetros termodinámicos de aceros v fundiciones.
Vinnakota Sriramulu. (2006). Estructuras de Acero Comportamiento y LRFD.
Zumba, E. (2024). INTRODUCCION A LA INGENIERIA DE MATERIALES metalicoszumba ESPOCH 2024. http://cimogsys.espoch.edu.ec/direccion-

publicaciones/public/docs/books/2024-07-22-144018-ingenieria%20de%20materiales.pdf
Zumba-Novay, E., & Merizalde-Salas, A. (2023). Optimization of the manufacturing process by 3D printing of the glass lift handle in Chevrolet Aveo Family. In Chevrolet Aveo Family. Repique (Vol. 5, Issue 1). https://orcid.org/0000-0002-2121-8418