International Journal of Scientific Research in Science, Engineering and Technology
Print ISSN: 2395-1990 | Online ISSN : 2394-4099 (www.ijsrset.com)
doi : https://doi.org/10.32628/IJSRSET207615

A Detailed Comparison of Various Steel Types - Stainless Steel, Structural Steel and Aluminum Steel

Adekoya Oluwaseun Abiodun[1], Oluwasegun M. Ayoola[2], Taofeeq O. Olajire[3], Oluwatimilehin E. Oluwajire[4], Olawale J. Abidakun[5]

[1]Department of Mechanical Engineering, University of Cincinnati, Ohio, USA
[2]Department of Mechanical Engineering, Federal University of Technology, Akure, Ondo State, Nigeria
[3]Department of Agricultural Engineering, Ladoke Akintola University of Technology, Nigeria
[4]Department of Mechanical Engineering, Federal University of Technology, Akure, Ondo State, Nigeria
[5]Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Ondo State, Nigeria

Article Info
Volume 7 Issue 6
Page Number: 103-109
Publication Issue :
November-December-2020

Article History
Accepted : 25 Nov 2020
Published : 05 Dec 2020

ABSTRACT

Steel, compared to iron is an alloy of iron with commonly a few percent of carbon to enhance its strength and fracture resistance. The use of stainless steel in the design of structures remains a relevant discussion across different areas. In fact, the importance of structural steel in the glocal world has applications in virtually every sector. Also, aluminum steel has been used widely in residential applications, commercial buildings, and vehicular (automotive) designs. A close comparison of these three sheets of steel will give enlightenment about what brings them together and their applications for such characteristics they possess that seem alike. Many researchers argue about the possibility of their sustainability both in terms of cost, availability, fire resistance, and fabrication. Understanding their behaviors following their comparison will provide accurate answers to these propositions. This paper compares the stainless, structural, and aluminum steels in terms of usage, properties (chemical and mechanical), compares exclusively the structural and stainless steel design provisions, reviews recent research activities, and highlights the important developments.

Keywords : stainless steel, structural steel, aluminium steel, corrosion, mechanical properties

I. INTRODUCTION

Steel is the yardstick of the modern developed environment. It is the world's second-largest commodity value chain after crude oil [4] underpinning daily life. And as climate change and the energy transition are becoming the order of the day, steel will evolve as a building block of global correction and control of carbonization efforts across all key sectors of countries in the world. The steel industry to be specific has an important part to play in reducing its own emissions, which are around 7-10% of global greenhouse emissions [4]. The ability of the steel industry in decreasing these will play a vital part in the global challenge to decarbonize economic activity without any detriment in terms of future living standards.

Stainless steel is a group of iron-based alloys containing 10.5% or more chromium [10], a constituent that prevents the iron from rusting, which also provides heat-resistant properties. All stainless steels have a magnificent resistance to corrosion. This resistance to susceptibility is due to the congenitally occurring chromium-rich oxide film formed on the surface of the steel. Although extremely thin, this invisible, inert film is tightly adherent to the metal and severely protective in a wide range of corrosive media. The film is rapidly self-repairing in the presence of oxygen, and impair by abrasion, cutting, or machining is quickly repaired. Stainless steel resistance to ferric oxide formation occurs from chromium present in the alloy, which results in a passive film that protects the essential material from corrosion attack, and has self-healing ability in the presence of oxygen. Corrosion resistance capability is often improved by:

1. Increasing the content level of the chromium above 11%;
2. Addition of 8% or more amounts of nickel; and
3. Molybdenum addition (that emends resistance to “pitting corrosion”). [2]

Adding nitrogen also does not allow pitting corrosion and improves mechanical strength. So, numerous varieties of stainless-steel with differing metallic elements (chromium and molybdenum) compositions align with the atmosphere the alloy will face up to. Combat with corrosion and stain, low or no maintenance, and known refulgence make stainless steel a typical material for many applications where the steel’s strength and corrosion resistance are required. Furthermore, stainless steel can be rolled into sheets, plates, bars, wire, and tubing. These can be used in culinary applications, surgical equipment, main appliances, construction materials in large and high buildings, industrial equipment, and storage tanks and tankers for chemicals and food products. Stainless steel has been formally acknowledged as a potential solution to structural and mechanical engineering problems [13]. Many scholars have presumed that their high initial cost is outrageous but as reported they are not as expensive in comparison to their life cycle cost because if calculations are done appropriately in design selection and choice of materials, it results in minimum cost over the whole life of a project [2].

Structural steel is a form of steel used basically for making construction materials in a variety of shapes. Engineers over the years in their decisions have wrought more projects considering more of structural steel than concrete because of the sustainability of steel in terms of fabrication and easy recycling from metal making them relatively cheap with high strength to weight ratio. Several steel shapes take the shape of an elongated beam with a particular cross-section. Many steel shapes, possess grand second moments of space, which makes them terribly stiff with regard to the cross-section space and then will support high masses while not severe lax [3]. Steel shapes, volume, mechanical properties and chemical compositions are controlled by patterns in almost economically based nationalities [3]. Aluminized steel always has a hot dip coating on either side with an aluminum and silicon metallic alloy. This method assures a decent scientific discipline bond between the steel sheet and its metal coating, manufacturing fabric with a singular combination of properties possessed neither by steel nor by metal alone. Aluminized steel shows a stronger behavior against corrosion and keeps the properties of the bottom material steel for temperature not up to 800 °C (1,470 °F) [1].

Therefore, no serious scholarly comparisons of these three sheets of steel have been done to bring them to one in terms of properties and applications. These comparisons are addressed throughout this paper.

II. MATERIALS AND METHOD

Here we consider the properties, factors for the choice of materials, and applications of the subject matters. Because of the limited usage of aluminum steel, most of the comparisons here will be more stainless steel and structural steel.

Mechanical Properties

Stainless steel connections make use of welding, bolting, and other mechanical fasteners. Fundamental design ideology is no different from that for carbon steel joints and the high ductility that stainless steel offers, especially the austenitic grades, should be of utmost importance. The overall grades of stainless steel are so weldable; the austenitic grades particularly, can be welded with ease, and since no changes occurr in metallurgical structure with temperature, the weld material, and its surrounding zone must stay tough and ductile. Stainless steels (mostly the austenitic grades) show very high ductility and impact resistance. It is indeed particularly befitted to applications where ductility and impact resistance are sacrosanct, such as offshore structures, crash barriers, and structures susceptible to blast loading, and has been directed to railway carriage construction. The level of ductility of stainless steel hinges on the material composition, heat treatment, and degree of cold-work that the section has been subjected to, with reduced ductility for increasing cold-work. Stainless steel shows a radial stress-strain curve, without acute yield point, right smart strain hardening, and high malleability. For the conventional primary solid solution stainless steel types, the malleability (strain at fracture) is some forty to sixty percent.

Structural steel has high yield strength, stiffness, toughness, and ductile properties. Due to their constructability, they will be developed into almost any form that is either fast or welded along in construction. Structural steel can be erected immediately on the site as they are schedule-friendly construction materials. Also, in combining structural steel and reinforced concrete, structural steel is used to provide steel's tensile strength. Also, Aluminum steel was modeled for giving additional structural sturdiness and high yield strength in extremely corrosive mediums. Therefore, stainless and structural steel are both highly ductile and support welded regions while Aluminium and structural steel possess high yield strength whereas stainless steel has no sharp yield point.

Corrosion resistance

Stainless steels do not suffer uniform corrosion when exposed to wet environments. In comparison, stainless steels chiefly contain sufficient chromium to undergo passivation (state of being unaffected by corrosion), spontaneously forming a minute thin inert surface film of chromium oxide by reaction with the oxygen in the air and even the little amount of dissolved oxygen in the water. This passive film further prevents corrosion by blocking oxygen diffusion to the steel surface and thus forestalls corrosion from promulgating into the bulk of the metal. This film is self-repairing, even when temporarily disturbed by a disorderly condition in the environment that surpasses the inherent corrosion resistance of that grade.

Structural steel in contact with water can corrode, causing dangerous structures. Measures should be taken in structural steel construction to deter any lifetime corrosion. To avoid this, the steel can be painted, so providing water resistance. Also, water-resistance material used to enclose steel is commonly water-resistant. Aluminum steel is highly corrosion-resistant because of the aluminum and silicon thin layers, which keep the basal steel from oxidizing. Thin layers also resist pit corrosion from occurring, particularly during exposure to salts that affect most other metals. Still, the nice corrosion opposition of aluminum steel, when the aluminized steel layer is broken and also the steel is opened, then the oxidization of steel and corrosion would positively occur.

So, both stainless steel and aluminum steel are highly corrosion-resistant, and structural steel is literally not resistant but can be made to resist corrosion.

Fire resistance

When chromium is added to stainless steel, this remains the most known method to increase high-temperature corrosion resistance in stainless steel; the reaction between chromium and oxygen forms a chromium oxide scale, which lowers the diffusion of oxygen into the material. The minimum 10.5% addition of chromium in stainless steels provides resistance of up to approximately 700 °C (1,300 °F), while 16% chromium addition provides resistance up to approximately 1,200 °C (2,200 °F). The most common grade of stainless steel with up to 18% chromium is resistant to about 870 °C (1,600 °F) [2].

Structural steel loses its strength when heated quite sufficiently. The essential temperature is often thought-about the temperature at when its yield stress has been reduced to sixty percent of the area-temperature yield stress [3].

Aluminized steel attainable finish uses are ovens, water heaters, ranges, baking pans, fireplaces, etc, [1]. Aluminized steel will face up to 550°C, 1022°F, with virtually no amendment within the base material. But due to silicon content, it develops black spots. Aluminized steel has slowly begun to convert bake house trays that were antecedently created by galvanized steel because it does not contain lead that is toxic. Overall, steel does not possess enough strength to withstand heat or fire over a long period of time.

Sustainability

The average carbon footprint of stainless steel of all types in all countries of the world is estimated to be 2.90 kg of carbon dioxide per kg of stainless steel produced in which 1.92 kg are emissions from raw materials consisting of chromium, nickel, and molybdenum; 0.54 kg emissions from electricity and steam, and 0.44 kg direct emissions from the stainless steel plant [2]. Note that stainless steel produced in countries that use cleaner sources of electricity such as nuclear energy will have lower carbon remains. Ferritics with no Nickel will have a reduced carbon dioxide track than austenitic with about 8% Ni or more.

Carbon footprint must not be only related to only sustainability factor in order to decide the choice of materials:

1. Over any product life cycle, maintenance, repairs or early end of life can increase its overall remains greater than the original material differences. Moreover, service loss for especially bridges may engender large unforeseen costs, such as queues, wasted fuel, and loss in man-hours.
2. The frequent usage of material provides a given service proportional to the performance, like the strength level, which allows lighter structures and components.
3. Stainless steel is totally recyclable [2]. Traditional stainless steel consists of 60% recycled material of which 40% originates from end-of-life merchandise, whereas the remaining 60% comes from producing processes. What precludes a high recycling composition is the accessibility of stainless steel scrap, despite a very high recycling rate. Taking a cue from the International Resources Panel's Metal Stocks in Society report, the per capita stock of stainless steel in use in a more developed society is 80–180 kg and 15 kg for a less-developed society. There is an auxiliary market that recycles usable

scrap for many stainless steel markets. The product is always coil, sheet, and blanks. This material is bought at a less-than-high price and sold to commercial quality stampers and sheet metal houses. The material may have dents, scratches, or pits but is made to the current specifications.

In structural steel sustainability – a wide range of construction companies and material distributors are becoming more environmentally friendly. Sustainability has become a completely new concentration for materials that will be in the environment for the coming generations. A sustainable material slightly affects the environment upon installation and over its life cycle. Structural steel is often tolerable when used in the rightful way. Over 80% of structural steel members are fabricated from recycled metals [3]. This component material is cheaper and has a higher strength to weight ratio than previously used steel components. To sum, both stainless steel and structural steel are highly sustainable.

Cost

In stainless steel, the Life cycle cost (LCC) calculations are used to choose the design and the materials that will lead to the least cost over the full lifetime of project, like a building or a bridge. The formula, in a very straightforward way, is as follows:

$$\mathrm{LCC} = \mathrm{AC} + \mathrm{IC} + \sum_{n=1}^{N} \frac{\mathrm{OC}}{(1+i)^n} + \sum_{n=1}^{N} \frac{\mathrm{LP}}{(1+i)^n} + \sum_{n=1}^{N} \frac{\mathrm{RC}}{(1+i)^n} \quad [2]$$

Where;

LCC = overall life cycle cost,

AC = acquisition cost,

IC = installation cost,

OC = operating and maintenance costs,

LP = cost of lost production due to downtime,

RC = materials replacement price,

N = planned lifetime of the project,

i = rate of interest and

n = year during which a selected RC or OC or LP can present itself.

The interest rate "i" is used to convert expenditures from different years to their present value so they can be added and compared fairly.

Application of LCC in materials selection

Stainless steel used in projects always results in lower LCC values compared to other matters. The higher acquisition cost (AC) of stainless steel components are often controlled by changes in operating and maintenance costs, downgraded loss of production (LP) costs, and the higher second-hand value of stainless steel components. LCC calculations are usually limited when considering any ongoing project. Nevertheless, there may be other costs that a project manager may consider:

- ✓ Utilities, such as plants, water supply, and waste treatment, and hospitals, cannot be shut down. Any maintenance will incur extra costs associated with the continuing service.
- ✓ Indirect community costs may be incurred in some situations such as mitigating traffic on bridges, making queues, delays, loss of working hours to the people, and increased pollution by idling vehicles.

In structural steel, the cost of construction materials will depend solely on the geographical location of the project and the availability and accessibility of the materials to be used. Just as the price of petrol fluctuates, so do the prices of cement, aggregate, steel, etc. Steel is sold by weight; the structural designer must specify the lightest members possible while maintaining a safe structural design. Utilizing several identical steel members instead of several distinctive ones conjointly reduces price.

So, the overall costs of designs that consist of stainless steel and structural steel are relatively low.

Applications

1. **Construction and Aesthetic appeal**: Stainless steel is available in many surface finishes. It is easily and simply maintained resulting in high quality, pleasing appearance [10]. The use of stainless steel in buildings can be both practical and aesthetic (artistic and attractive). Stainless steel is used in the construction of new generation buildings, such as the Petronas Twins Towers and the Jin Mao Building [2]. Due to their low reflectivity, stainless steel is used as a roofing sheet for airports, which prevents pilots from being veiled or blinded. It also keeps the surface of a roof close to ambient temperature. It is used for pedestrian and road bridges in the form of bars, plates, or tubes. There is a wide range of stainless steel applications for the construction of bridges. In structural steel, the tallest structures today (called "skyscrapers" or "high-rise") are constructed using structural steel largely due to its constructability, and also its high strength-to-weight ratio. However, this advantage of structural steel becomes voided for low-rise buildings or those with many stories or less. Low-rise buildings disseminate much smaller loads than high-rise structures, making concrete an economical alternative. This is particularly true for simple structures, such as parking garages, or any building that is an unsophisticated shape. Aluminized steel is used for some applications in the building, commonly used for heat exchangers in residential furnaces, commercial rooftop heating, ventilation, and air conditioning units.
2. **Vehicles and Automobiles**: The greatest use of stainless steel in cars is the exhaust line. They are used for the collector, tubing, muffler, catalytic converter, and tailpipe. Likewise, the stainless steel heat resistance is utilized in the elements of turbochargers, whereas alternative heat-resisting grades are used for exhaust gas recirculation and for body of water and exhaust valves [2]. Stainless steel has been the best choice for multifarious applications, such as stiffeners for windshield wiper blades, balls for seat belt operation device in case of accident, springs, fasteners, etc. Many automobile manufacturers use stainless steel as decorative highlights in their vehicles. Structural steels used for building construction in the US use standard alloys identified and specified by ASTM (American Society for Testing and Material). These steels have an alloy identification starting with A and then two, three, or four figures. The four-digit AISI steel types are ordinarily used for engineering, machines tools, and automobiles are a totally different kind of series. Aluminum steel manages the toughness of high-alloy steel, however is cheaper to supply than high-alloy steels and therefore is that the most well-liked material for producing automobile and bike exhaust gas systems.
3. **Culinary**: Stainless steel is often chosen for kitchen sinks because of its robustness, durability, heat resistance, and easy cleaning. In better prototypes, acoustic (music) noise is restrained by applying resilient undercoating to dampen vibrations. The material is also used for covering surfaces such as appliances and backsplashes. Cookware and bakeware may be clad in stainless steels to improve their cleanability and durability and to allow their use in induction cooking. Because stainless-steel may be a poor conductor of warmth, it is used as a skinny surface facing over a core of copper or aluminum that without delay conducts heat. Cutlery is always made of stainless steel, for low corrosion, ease of cleaning, little toxicity, and ability to avoid reacting with the food by electrolytic activity. Aluminum steel is used as

ovens, kitchen ranges, water heaters, fireplaces, barbecue burners, and baking pans. This steel is used for heating things up because it transfers heat faster than most other steels. To sum up, Stainless steel and aluminum steel are used widely for culinary purposes.

III. CONCLUSION

This paper identifies and introduces the various applications of the steels in the subject. So far, these sheets of steels have been used for machine tools, building machine parts, development of the building, manufacture of surgical equipment, kitchen utensils, and vehicular, automotive, and aircraft applications. Therefore, we see that stainless steel is excellent for designing and producing surgical tools while in the development of buildings, it is advisable to use Aluminum and structural steel. For machine parts, building structural steel does it better compared to the other two. The comparisons we discussed in this paper make it easy to access information about these steel in a single entity.

IV. ACKNOWLEDGEMENT

The authors are grateful to the Department of Mechanical Engineering, School of Engineering and Engineering Technology, The Federal University of Technology, Akure, Ondo State, Nigeria for providing appropriate support used for the study. The authors are also sincerely grateful to the Department of Agricultural engineering for some other resources used in this study.

V. REFERENCES

[1]. "Aluminized steel" – Wikipedia. Retrieved November 6, 2020, from en.m.wikipedia.org/wiki/Aluminized_steel
[2]. "Stainless steel" – Wikipedia. Retrieved November 6, 2020, from en.m.wikipedia.org/wiki/Stainless_steel
[3]. "Structural steel" – Wikipedia. Retrieved November 6, 2020, from en.m.wikipedia.org/wiki/Structural_steel
[4]. "BHP" – LinkedIn. Retrieved November 6, 2020, from https://www.bhp.com
[5]. Mann, A. P. The structural use of stainless steel. The Structural Engineer. 1993, 71:4, 60-69.
[6]. EN 10088-1. Stainless steels – Part 1: List of stainless steels. CEN. 1995.
[7]. The Sustainable Construction Task Group. The UK Construction Industry: progress towards more sustainable construction 2000-2003. 2003.
[8]. "385278006 Advantages of Aluminium" – SCRIBD. Retrieved October 29, 2020
[9]. "305582756 Structural Steel" – SCRIBD. Retrieved October 29, 2020
[10]. "6582140 Stainless Steel" – SCRIBD. Retrieved October 29, 2020
[11]. SABS. Structural use of steel – Part 4: The design of cold-formed stainless steel structural members. SABS 0162-4:1997. 1997.
[12]. Mazzolani, F. M. Aluminium Alloy Structures. 2nd Edition. E & FN Spon, An imprint of Chapman and Hall. 1995.
[13]. Gardner, L. (2005). The use of stainless steel in structures. Progress in Structural Engineering and Materials. 7(2), 45-55.
[14]. "stainless steel 191171765" – SCRIBD. Retrieved October 29, 2020

Cite this article as :

Adekoya Oluwaseun Abiodun, Oluwasegun M. Ayoola, Taofeeq O. Olajire, Oluwatimilehin E. Oluwajire, Olawale J. Abidakun, "A Detailed Comparison of Various Steel Types - Stainless Steel, Structural Steel and Aluminum Steel", International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET), Online ISSN : 2394-4099, Print ISSN : 2395-1990, Volume 7 Issue 6, pp. 103-109, November-December 2020. Available at doi : https://doi.org/10.32628/IJSRSET207615
Journal URL : http://ijsrset.com/IJSRSET207615