A Review Paper on Study of I-Section with Different Grades of Stainless Steel

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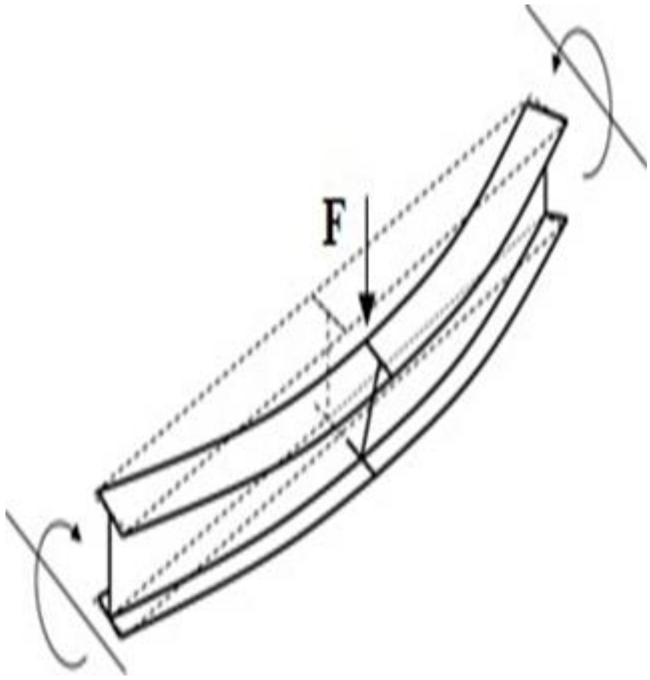
***Abstract** - The demand for stainless steel has been increasing rapidly over the years due to its key features such as its corrosion resistance making it more durable than other construction materials. Since stainless steel has become an integral part of construction it is necessary to have a detailed analysis on the different grades of stainless steel and through this paper we compare and study the I-sections made of different grades of stainless steel and determines the most efficient grade of stainless steel. This comparison was made possible by observing the results obtained from various experimental and numerical investigations of these different grades of stainless steel. A recently developed grade, known as lean duplex stainless steel proved to be the most efficient grade of stainless steel.*

Keywords: I-Section, Stainless Steel, Martensitic, Austenitic, Ferritic, Duplex

1.INTRODUCTION

Stainless steel has been scarcely, but increasingly used in structures as it offers a range of benefits over conventional carbon steel due to its high corrosion resistance, large tensile and compression strength, high ductility and better impact resistance. Stainless steels are classified according to their metallurgical structure. The structure may be composed of the stable phases: ferrite or austenite, a "duplex" mix of these two, forms martensite or a structure which is hardened containing micro-constituents which are precipitated. Also engineers use I beams of different grades of stainless steel widely in construction for forming columns and beams of many different lengths, sizes, and specifications. This is due to its high functionality. The shape of I-section makes them excellent for unidirectional bending parallel to the web. The web resists the shear stress while horizontal flanges resist the bending movement. These I-sections can resist buckling, take various types of loads and shear stresses. Since the "I" shape is an economic design that doesn't use excessive quantity of steel making them cost effective. This paper compares 'I sections made of different grades of stainless steel' from the results obtained from various numerical and experimental investigations and proposes the most efficient grade of stainless steel I section.

1.1 Failures in I-Sections



(a) Lateral Torsional Buckling

Fig -1: Lateral bending in I section

When an applied load causes both lateral displacement and twisting of a member then it is said to undergo lateral torsional buckling. This failure occurs when a load is applied to an unconstrained, steel I-section, with both the flanges acting differently, one under tension and the other under compression. The applied vertical load results in tension and compression in the flanges of the section. The tension flange tries to keep the member straight while the compression flange deflects from its original position laterally.

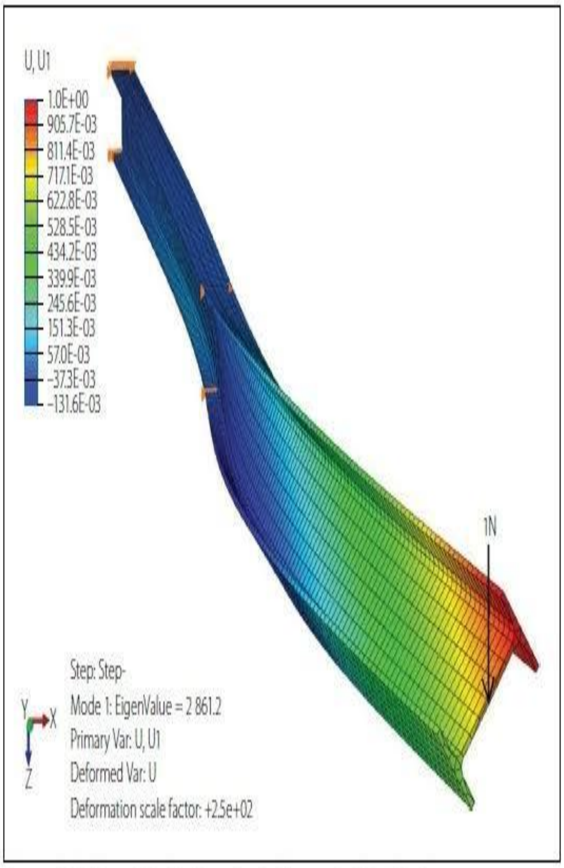


Fig -2: Laterally Buckled I section

If the section has to be remained straight the restoring forces created due to the lateral bending of the section should be opposed. The restoring forces are not large enough to prevent the lateral deflection of the section.

The bucking resistance of the beam can be determined by the lateral component of the tensile forces along with the restoring force. The forces within the flanges also cause the beam to twist along its longitudinal axis, in addition with the lateral movement of the section. The twisting of the section is fully resisted by the torsional stiffness of the beam section. The torsional stiffness influence is mainly due to flange thickness of the section. That is why a section with thicker flanges has a larger bending strength than the same depth of section with thinner flanges.

(b) Lateral Bending and Deflection

The force acting upon the beam due to external loads, span of the section, self-weight is called bending moment . The beam theory shows that I sectional area is more effective in bearing both shear and bending loads.

Due to combine concentrated and uniform distributed load (self-weight) applied over the span of the simply supported I section beam, the beam changes its equilibrium position and permanent deformation is occurred at the mid span of the beam and it is known as deflection.

(c) Shear Centre and Warping

The Shear Centre is the point in the cross-section through which the transverse loads must pass to produce bending without twisting, it is also known to be the centre of rotation, when only pure torque is applied.

It is presumed that during twisting of circular bars subjected to torsion cross section remain plane. Nevertheless, when member with cross section like solid I channel are subjected to torsion, the warping take place at the cross section. Warping is the out of plane damaging of cross area when a part is subjected to torsion.

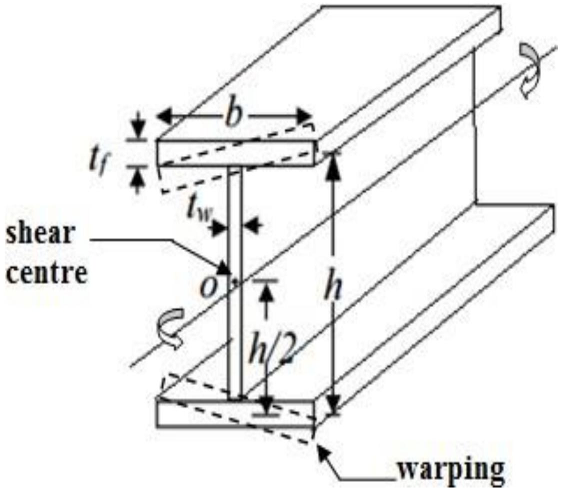


Fig -3: Warping occurs in I section beam

1.2. Different grades of stainless steel

The stainless steel is a type of low carbon steel in which chromium content is present in it. The unique stain and corrosion resistance properties is mainly due to the presence of chromium content in it. The chromium content in the steel also permits the formation of a rough, microscopic, corrosion resisting chromium oxide film on the surface of the steel section. In addition to chromium the other elements like molybdenum, nickel and nitrogen helps to increase corrosion resistance and other properties. Even though the corrosion resistance of stainless comes from the existence of Chromium, other elements are added to increase other properties. These elements change the microstructure of the steel. Stainless steels are normally grouped into five different classes.

(a) Martensitic Stainless Steel

Martensitic Stainless grades are category of stainless alloys made to be corrosion resistant and harden-able. All martensitic grades are a type of chromium steels without nickel. All these grades show magnetic properties. Martensitic grades are provided where hardness, strength, and wear resistance are required.

•Type 410: It is a basic type of martensitic grade that contains lower alloy content. It has a relatively low cost and it is a heat treatable stainless steel. These are used typically where corrosion is not too severe (such as air, water, some chemicals, and food acids.). Some of the applications of this grade is, using it as a fastener which needs a combination of strength and corrosion resistance.

•Type 410S: It contains lower carbon content than Type 410, but it provides increased weldability with lower hardenability. This is a general-purpose heat and corrosion resisting chromium steel.

•Type 414: This type provides more corrosion resistance due to increased Nickel content (2%). This grade is typically used for springs and cutlery.

(b) Ferritic Stainless Steel

These grades have resistance against corrosion and oxidation, at the same time it provides resistance to stress and cracking. While these steels are magnetic, they cannot be hardened using heat treatment. Once annealed these grades can be cold worked. They have a higher resistance to corrosion than martensitic grades but are mostly lesser than austenitic grades. These grades are straight Chromium steels with no Nickel content and are often used for kitchenware and certain automotive applications such as exhaust systems.

•Type 430: This is a basic type grade which is less corrosion resistant than Type 304. This type has a resistance to corrosives like nitric acid, sulfur gases, and many organic acids.

•Type 405: This type of grade has lower chromium content combined with added aluminum. This chemical composition helps to prevent hardening when it is cool down from high temperatures. The applications of these grades include heat exchangers.

•Type 409: These grades are least expensive because of its decreased chromium content. This type should only be used for interior or exterior parts in stable corrosive environments.

(c) Austenitic Stainless Steel

Austenitic is the most commonly used class of stainless steel. The high nickel and chromium content of the grades in this group provide superior corrosion resistance and impressive mechanical properties. They can be hardened considerably through cold-working and cannot be hardened through heat treatment. Magnetic properties are absent in all the grades in this class. The standard grades of austenitic stainless steel contain a maximum of 0.08% carbon and there is no minimum carbon requirement.

- **Type 304**: One of the most common type austenitic stainless steel grade. Its high content of nickel and chromium make it a preferred choice when making processing equipment for the chemical (mild chemicals), food/dairy and beverage industries. This grade possesses an excellent combination of corrosion resistance, fabric-ability and high strength.
- **Type 316**: This Stainless grade contains 18% chromium, 14% Nickel and added Molybdenum. These elements increases its resistance to corrosion.
- **Type 317**: It contains higher percentage of molybdenum than 316, it is used in highly corrosive environments.

(d) Duplex Stainless Steel

These grades are a combination of Ferritic and Austenitic material. Duplex grades are about twice as strong as the austenitic and ferritic grades. They have better toughness and ductility than the ferritic grades, but they do not reach the levels of the austenitic grades. Duplex grades have resistance to corrosion close to the austenitic grades such as 304 and 316.The most widely used grade of Duplex stainless steel is Grade 2205.

•Type 2205: These are mostly suited for high-pressure and highly corrosive environments. It has high corrosion and erosion fatigue properties.

•Type 2304: This grade is generally used in the same applications in which Alloys 304 and 316L are used. It also has corrosion resistance slightly better than austenitic grades 304 and 316.

•Type 2507: Duplex 2507 is a type of super duplex stainless steel. It has high chromium, molybdenum, and nitrogen levels which helps to provide excellent resistance to general corrosion pitting, and cracks.

(e) Precipitation-Hardening (PH) Stainless Steels

These grades of stainless steel can be strengthened and hardened by heat treatment. This helps the designer to have a unique combination of fabric-ability, strength, ease of heat treatment, and corrosion resistance that are not commonly seen in any other class of material. These grades comprise of 17Cr-4Ni (17-4PH) and 15Cr-5Ni (15-5PH).

•Type 17-4: Alloy 17-4 is a chromium-copper precipitation hardening stainless steel that is most commonly used for applications that requires high strength and medium level of corrosion resistance

•Type 15-5: The 15-5 alloy has greater toughness than 17-4. This grade is a variant of the older 17-4 chromium-nickel-copper precipitation hardening martensitic stainless steel.

Stainless Steels

Typical composition of austenitic stainless steel - Type 304 and 304L

Material	Iron	Carbon	Chromium	Nickel	Phosphorus	Manganese
304	Bal.	<0.08%	18,00%	8,00%	<0.045%	<2%
304L	Bal.	<0.03%	18,00%	8,00%	<0.045%	<2%

Typical composition of ferritic stainless steel - Grade 430

Material	Iron	Carbon	Chromium	Nickel	Phosphorus	Manganese
Grade 430	Bal.	0,12%	17,00%	0,50%	<0.04%	<1%

Typical composition of martensitic stainless steel - Grade 440C

Material	Iron	Carbon	Chromium	Nickel	Silicon	Manganese
Grade 440	Bal.	1,10%	17,00%	0,50%	1,00%	1,00%

Typical composition of duplex stainless steel - SAF 2205

Material	Iron	Carbon	Chromium	Nickel	Molybdenum	Manganese
2205	Bal.	0,03%	22,00%	5,00%	3,00%	2,00%

Typical composition of PH stainless steel - 17-4PH

Material	Iron	Carbon	Chromium	Nickel	Copper	Niobium
17-4PH	Bal.	0,07%	17%	4%	4%	0,45%

Table 1: Compositions for different grades of stainless steel

2. LITERATURE REVIEW

Numerical Simulation and Design of Stainless Steel Hollow Flanged I-Section under Shear, A. D.M.M.P. Dissanayake, C. Zhou, J.Guss (2021)

They studied the structural behaviour of stainless-steel hollow flange beams under bending and shear. Both experimental and numerical study was conducted. The numerical study was conducted using Abaqus software. The obtained results were then compared with the existing Eurocode provision. Study was carried on austenitic grade steel with hollow flanges alone. The result showed that the codal provision are conservative in design predictions in the case of stainless steel.

Flexural Buckling Behaviour and Design of Ferritic Stainless Steel I-Sections, B. Kucukler, Merih (2020)

Flexural buckling behaviour and design of ferritic and duplex stainless steel I section columns were studied. Here Duplex and ferritic stainless steel I section were tested. Experimental and numerical analysis were done on this section and the results were compared with EN 1993-1-4. EN 1993-1-4 leads to the most accurate and reliable results relative to the existing stainless steel design standards and guides, it still provides overly conservative ultimate strength predictions in some cases. Here the analysis were done on Lean Duplex Stainless Steel and ferritic I-sections.

Behaviour and Design of Lean Duplex Stainless Steel Sections with Web Openings, C. Karma Hissey Lepcha, Allan Lambor Marbaniang (2020)

They studied the flexural behaviour of lean duplex stainless steel tubular sections with web openings. The study reveals the effects of the perforations on the bending capacity, deformed shapes and local buckling characteristics and also aims in particular for a comparison between sections having extended or circular openings with a wide range of section slenderness. Experimental and numerical analysis were conducted and results obtained was compared to American specification and European specifications. The effects of web openings with respect to the capacity and deformation profiles and shapes were found to be conservative. The direct strength method showed unconservative predictions. Modifications have been proposed to both the ASCE specification and the direct strength method for LDSS sections with web openings through this paper.

Experimental and Numerical Studies of S960 Ultra High Strength Steel I-Section, Yating Liang, Ou Zhao (2020)

To study the structural behaviour and resistance of S960 ultra high strength steel I-Section. Rectangular solid I-Section of Ultra High Strength steel were analyzed. Numerical and Experimental studies were conducted and obtained results was compared to Eurocode. Pin ended column test were carried out to determine the flexural buckling behaviour. The obtained results were employed to assess the applicability of the relevant design rules. The new proposed design buckling curve has higher degree of design accuracy and consistency.

Cross-sectional Behaviour of Cold-Formed High Strength Steel Circular Hollow I-Section, Xin Meng, Leroy Gardner (2020)

Here experimental and numerical investigation study on cross sectional behaviour of structural steel hollow section is carried out. Cold-formed high strength steel sections were tested. Experimental studies were conducted and were compared with American and Eurocode. The results revealed that the design equations for effective area and effective section modulus are somewhat conservative.

Flexural-Torsional Buckling of Austenitic Stainless Steel I-section, J. Leroy Gardner, Merih Kucukler, Yidu Bu (2019)

This paper investigates the flexural torsional buckling of austenitic stainless steel I- section and its responses are observed. Both numerical and experimental investigations were carried out. Finally, a new formula for the design of stainless steel I section beam-columns susceptible to flexural torsional buckling was proposed over the existing design provision as the new proposal yield increased accuracy and consistency.

Structural Performance of Cold-Formed Lean Duplex Stainless Steel Sections at Elevated Temperatures, Yuner Huang, Ben Young (2018)

They studied the structural performance of cold-formed lean duplex stainless steel sections under elevated temperatures. Cold-formed lean duplex stainless steel sections were analyzed at elevated temperatures varying from 24 to 900 °C. A finite element model was developed and numerical analysis was carried out. A modified direct strength method was used to design the cold formed lean duplex stainless steel flexural members as it provides more accuracy and reliability. The existing design rule was quite conservative in predicting the flexural strengths at elevated temperatures but the iterative calculation procedure was tedious.

Flexural Buckling of Lean Duplex and Austenitic Stainless Steel I-Section, Lu Xang, Fan-shag (2016)

They studied about the flexural buckling of welded Lean Duplex and Austenitic Stainless Steel I-section. Here Austenitic and Lean Duplex stainless steel I-section were tested. Numerical studies were conducted and obtained results was compared to Eurocode. Load displacement curves and buckling strength were compared. Here the analysis were done on Lean Duplex Stainless Steel and austenitic I-sections.

Tests of Cold Formed Duplex Stainless Steel Hollow I-Section G. Wiag-khan Lui, Ben Young (2014)

Here tests of cold-formed duplex stainless-steel square hollow section were conducted. Experimental studies were conducted and were compared to American code. As the results ultimate load capacities and interaction curves were obtained. Here analysis was done on Lean Duplex Stainless Steel hollow sections.

Cross-section Stability of Lean Duplex Stainless Steel I-Section, H. N.Saliba, L.Gardner (2012)

The cross-section stability of Lean Duplex Stainless Steel welded I-section were studied. Lean duplex stainless steel I-section are tested under bending and compression. Experimental and numerical analysis were conducted and the results are compared to Eurocode with codified method. The results from both experimental and numerical analysis were used to evaluate the applicability of existing design approaches to Lean Duplex Stainless Steel.

3. CONCLUSION

This study is mainly focusing on the determination of the most efficient grade of stainless steel I-section. The determination was made possible through analysing journals that performed both experimental and numerical tests on different grades of stainless steel I-sections. Experimental test include laboratory tests such as 3-point and 4-point bending tests, pin ended column tests, compressional tests and the numerical investigation was carried out using Abaqus software. The results obtained for each grade of stainless steel were then compared with each other and finally based on all these results and structural performances it was concluded that Lean Duplex Stainless Steel proved to be more efficient. Another major reason that contributed to this conclusion was it's low cost as it has far low nickel content than other grades. Along with it, LDSS possesses higher strength than the common austenitic stainless steels and other grades, accompanied with good corrosion resistance and high temperature properties and adequate weldability and fracture toughness. Here the test performed on LDSS were mainly compared to the test performed on austenitic, ferritic and duplex grades. Overall, good corrosion resistance, moderate cost and high strength of lean duplex stainless steel makes this material an valuable choice for structural applications.

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