STUDY ON BEHAVIOUR OF AUSTENITIC STAINLESS STEEL CHANNEL SECTIONS UNDER COMBINED WEB CRIPPLING AND BENDING ACTIONS

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Abstract: *. Austenitic stainless steel is relatively new material in the constructional industry. It found wide applications in the field of roofing, transmission towers and structural works apart from its economic perspective. The relevance of this study is that by better understanding of the behaviour of the material it is possible for the better utilization of the material. Web crippling and bending finite element models for austenitic stainless steel channels are developed using Ansys 2021 R1. The parameters like inside bent radius, bearing length, yield strength and thickness are considered and variation in crippling strength by varying each of these parameter is found out. Several papers which gave information regarding stress strain behavior of the material, initial imperfection used in modelling were also reviewed for creation of the analytical model.*

Keywords: **Austenitic Stainless steel, Crippling, Bending**

1. INTRODUCTION

Stainless steel is a family of iron-based alloys that contain a minimum of approximately 11% chromium, a composition that prevents the iron from rusting, as well as providing heat resistant properties. Different types of stainless steels include the elements carbon (from 0.03% to greater than 1.00%), nitrogen, aluminium, silicon, sulphur, titanium, nickel, copper, selenium, niobium, and molybdenum. In metallurgy, stainless steel is also known as inox steel.

The resistance of stainless steel to ferric oxide formation results from the presence of the chromium in the alloy, which forms a passive film that protects the underlying material from corrosion attack, and can self-heal in the presence of oxygen. Corrosion resistance can be increased further, by:

- Increasing the chromium content to levels above 11%,
- Addition of 8% or higher amounts of nickel. and
- Addition of molybdenum (which also improves resistance to "pitting corrosion").

Thus, there are numerous grades of stainless steel with varying chromium and molybdenum contents to suit the environment the alloy must endure. Stainless steel's resistance to corrosion and staining, low maintenance, and familiar lustre make it an ideal material for many applications where both the strength of steel and corrosion resistance is required. Stainless steels are rolled into sheets, plates, bars, wire, and tubing to be used in: cookware, cutlery, surgical instruments, major appliances; construction material in large buildings, industrial equipment (for example, in paper mills, chemical plants, water treatment); and storage tanks and tankers for chemicals and food products (for example, chemical tankers and road tankers). Stainless steel's corrosion resistance, the ease with which it can be steam cleaned and sterilized, and no need for surface coatings has also influenced its use in commercial kitchens and food processing plants.

1.1. Stainless steel families

There are five main families, which are primarily classified by their crystalline structure:

i. Austenitic stainless steels

ii.Ferritic stainless steels

iii.Martensitic stainless steels

iv.Duplex stainless steel

v.Precipitation hardening stainless steels

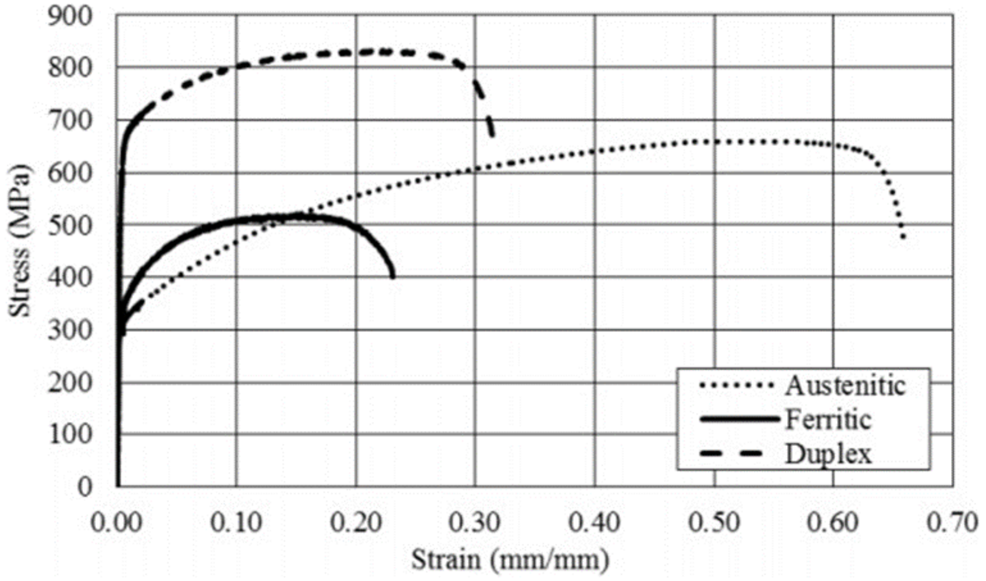

Figure 1. Stress- strain curves for various types of stainless steels (Arrayago et al., (2015))

1.2. Austenitic stainless steels

Austenitic stainless steel is the largest family of stainless steels, making up about two-thirds of all stainless steel production. These stainless steels possess austenite as their primary crystalline structure (face-centered cubic). This austenite crystalline structure is achieved by sufficient additions of the austenite stabilizing elements nickel, manganese and nitrogen. Due to their crystalline structure austenitic steels are not hardenable by heat treatment and are essentially non-magnetic. Austenitic stainless steels have many advantages from a metallurgical point of view. They can be made soft enough with yield strength 200 MPa to be easily formed by same procedures that work with carbon steel, but they can also be made incredibly strong by cold work, up to yield strengths of over 2000 Mpa. Their austenitic structure is very tough and ductile down to absolute zero. They also do not lose their strength at elevated temperatures. There are two subgroups of austenitic stainless steel. 300 series stainless steels achieve their austenitic structure primarily by a nickel addition while 200 series stainless steels substitute manganese and nitrogen for nickel, though there is still a small nickel content.300 series stainless steels are the larger subgroup. The most common austenitic stainless steel and most common of all stainless steel is Type 304, also known as 18/8 or A2. Type 304 is extensively used in such items as, cookware, cutlery, and also as structural members. Type 316 is the next most common austenitic stainless steel. Some 300 series, such as Type 316, also contain some molybdenum to promote resistance to acids and increase resistance to localized attack (e.g. pitting and crevice corrosion). The higher nitrogen addition in 200 series gives them higher mechanical strength than 300 series. Type 309 and 310 are utilized in high temperature applications greater than 800°C.Low-carbon versions, for example 316L or 304L, are used to avoid corrosion problems caused by welding. The "L" means that the carbon content of the alloy is below 0.03%.

1.3. Web crippling test

. Web crushing or crippling at points of concentrated or localized, load or reaction in thin-walled beams is well-known to be a significant problem. Steel sections are increasingly used in residential and commercial construction for both primary and secondary framing members. Such thin-walled sections are well-known to be susceptible to web crippling, particularly at points of concentrated load or reaction.It is a well-known fact that web elements of cold-formed steel members may fail due to crippling, that is buckle or yield, when subjected to local concentrated loads. This behaviour has been studied by numerous investigators since the 1940s, and it has been concluded that a purely theoretical analysis is rather complicated because it involves numerous influencing parameters.

There are six key parameters that influence the web crippling strength of steel members. These key parameters are the following:

a) Thickness of the web, t

b) Yield strength of the web, Fy

c) Web slenderness ratio, d/t

d) Inside bend radius to thickness ratio, r/t

e) Length of bearing to thickness ratio, N/t

f) Web inclination, θ

Also, the web crippling strength depends on the load position and whether or not only one flange is being loaded or two flanges. If it is end loading, the concentrated load is applied at the end of the member and in the case of interior loading, the concentrate load is applied somewhere in the middle of the member span

2. GEOMETRIC MODELLING

For the numerical study, the finite element general program ANSYS 2021 R1 is used. In order to simulate the web crippling behavior of the austenitic stainless steel channel sections, the channels, supporting blocks, as well as the applied loading condition including the bearing plates and support blocks were modelled. The geometric models of all specimens were created using the CAD software package Solidworks 16. All parts were created without merging each other in order to properly defining the contacts between each components of the experimental setup. In the previous works by Natario et al.,(2014), it was evident that geometric imperfections have minor effects on the ultimate web crippling capacity. The fact was also verified by Sundararajah et al.,(2017) and quantified that the effect of imperfections on the web crippling capacity is less than 1%. Therefore geometric imperfections were not considered in this study.

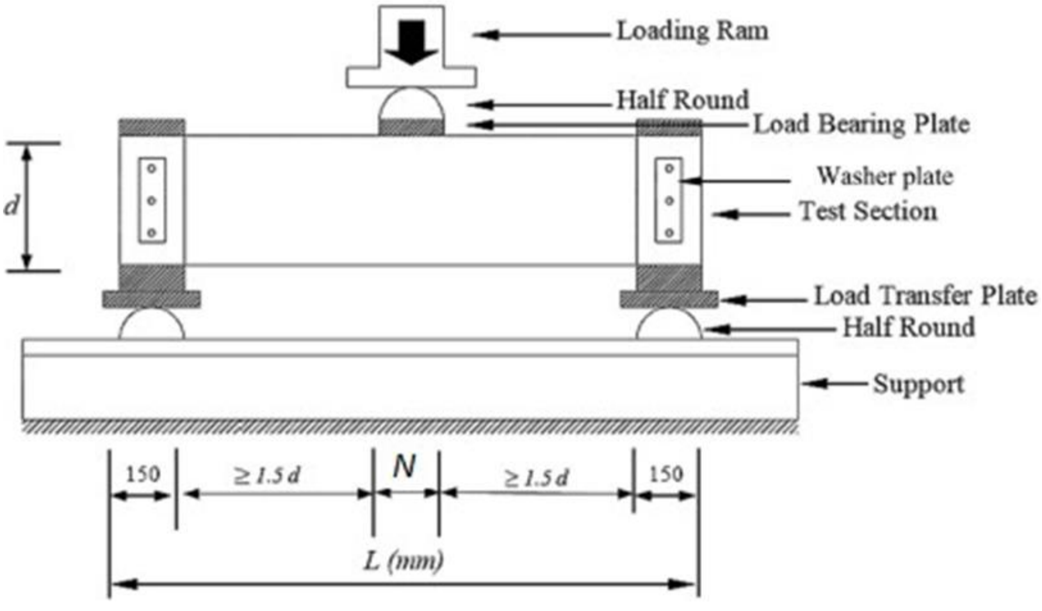

Fig 2. Front view of test setup

Where

d	=	Depth of web of the channel
bf	=	Flange width of channel
r	=	Inside bent radius
t	=	Thickness of the channel section
N	=	Bearing length

. The 3D solid model of the channel section generated in Solidworks 16 is converted to a 3d surface model in ANSYS SpaceClaim by using the mid surface generation., as the model of the channel section needed to be modelled as a surface for using the SHELL181 for discretization of the model.

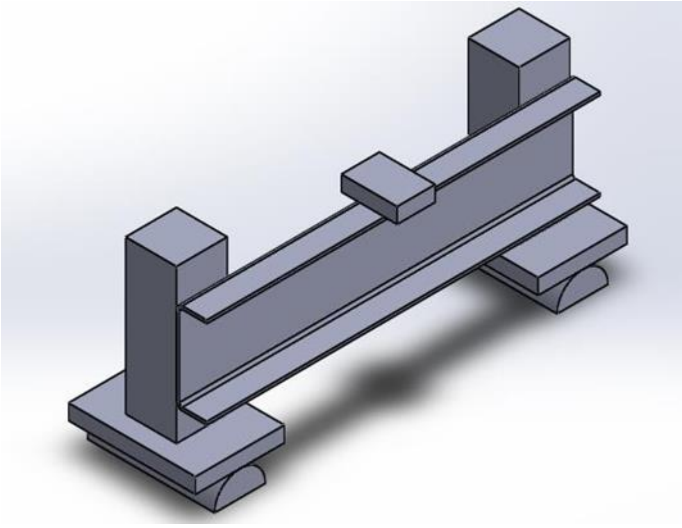

Fig 3. Geometry of the model in Solidworks 16

2.1. Element type

The SHELL181 thin shell element was used to model the channel sections. SHELL 181 is a four-node element with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes. (If the membrane option is used, the element has translational degrees of freedom only). It is suitable for analysing thin to moderately-thick shell structures. It is well-suited for linear, large rotation, and/or large strain nonlinear applications. Change in shell thickness can also be accounted for in nonlinear analyses.

The SOLID185 element is used to model the supporting blocks, loading plates and supporting half rounds. SOLID185 is used for 3-D modelling of solid structures. It is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyper-elasticity, stress stiffening, creep, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elasto- plastic materials, and fully incompressible hyper-elastic materials.

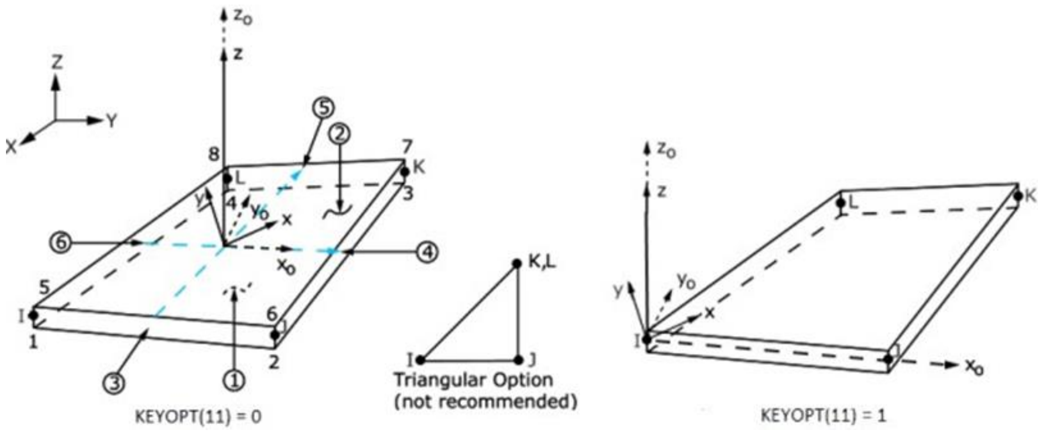

Fig 4. SHELL181 geometry

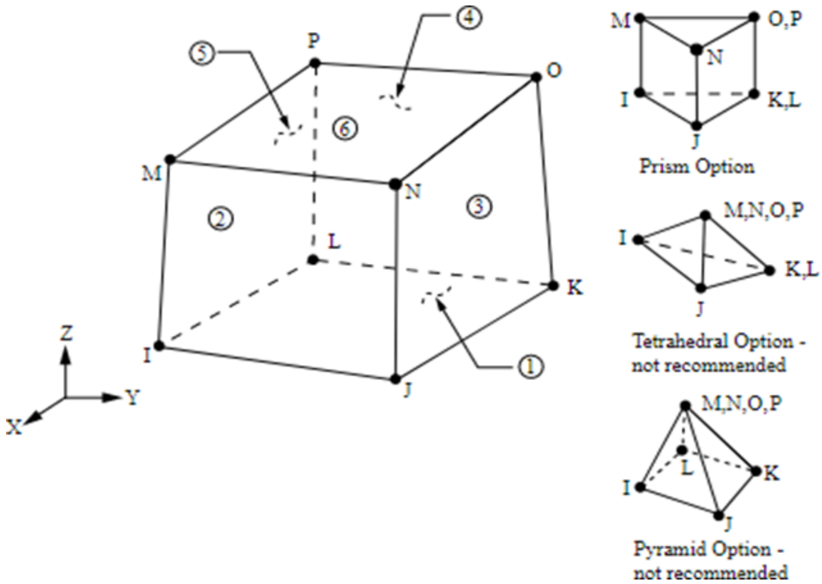

Fig 5. SOLID185 geometry

3. MATERIAL PROPERTIES

The channel sections were fabricated using Stainless steel (NL) material available in the general non-linear material library of ANSYS. The plasticity characteristics for the model were provided by using bilinear isotropic hardening property. The stress-strain curve obtained for stainless steel is shown below in figure In bilinear isotropic hardening model the stress-strain curve of a material can be achieved by inputting two parameters, yield strength and tangent modulus. The yield strength is one of the parameters considered in this study.

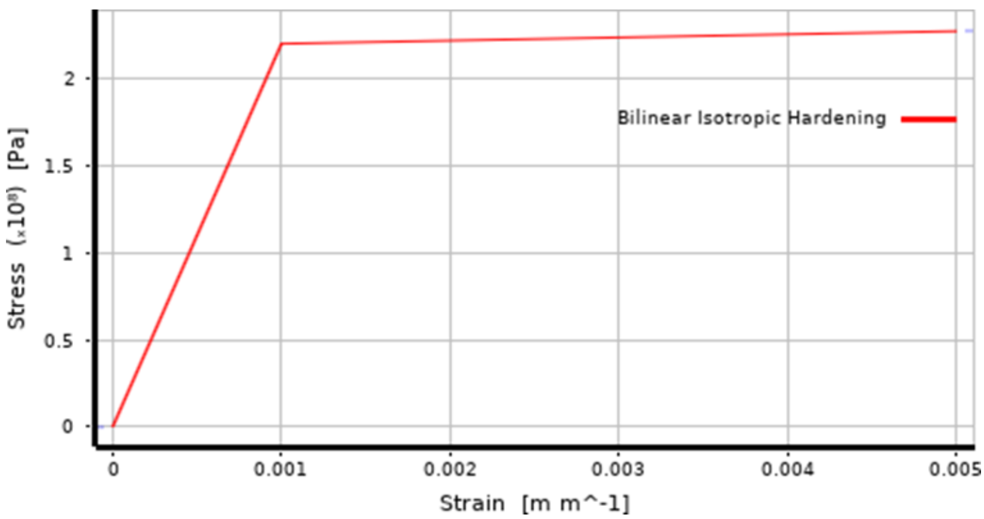

Fig 6. Bilinear stress-strain curve for stainless steel from ANSYS

The bearing plates were designed using the default structural steel available in ANSYS 2021 R1. The supporting blocks, loading plates and half rounds were modelled as rigid bodies

3.1 Finite element validation

The web crippling strength of the austenitic stainless steel channel sections under IOF loading condition obtained from the developed finite element model is compared with the past experimental data by Yousefi et al., (2020) in order to check and verify the accuracy of the developed finite element model.

On performing finite element analysis on the developed models under IOF loading conditions similar failure patterns were observed as in experimental setup. The results of the 2 specimens validated against the experimental data are tabulated below along with comparison with experimental data.

Specimen	P_{EXP} (KN)	P_{FEM} (KN)	Error (%)
175 x 60 x6	93.5	92.3	1.2
200 x 75 x4	54.46	53.41	1.9

Table 1. Validation results

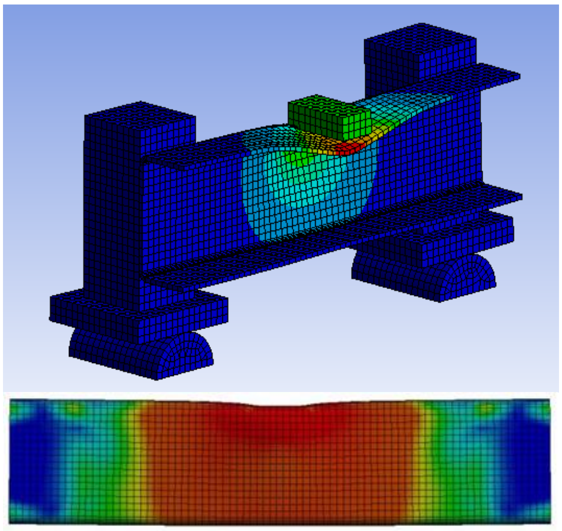

Fig 7. Failure pattern in ANSYS

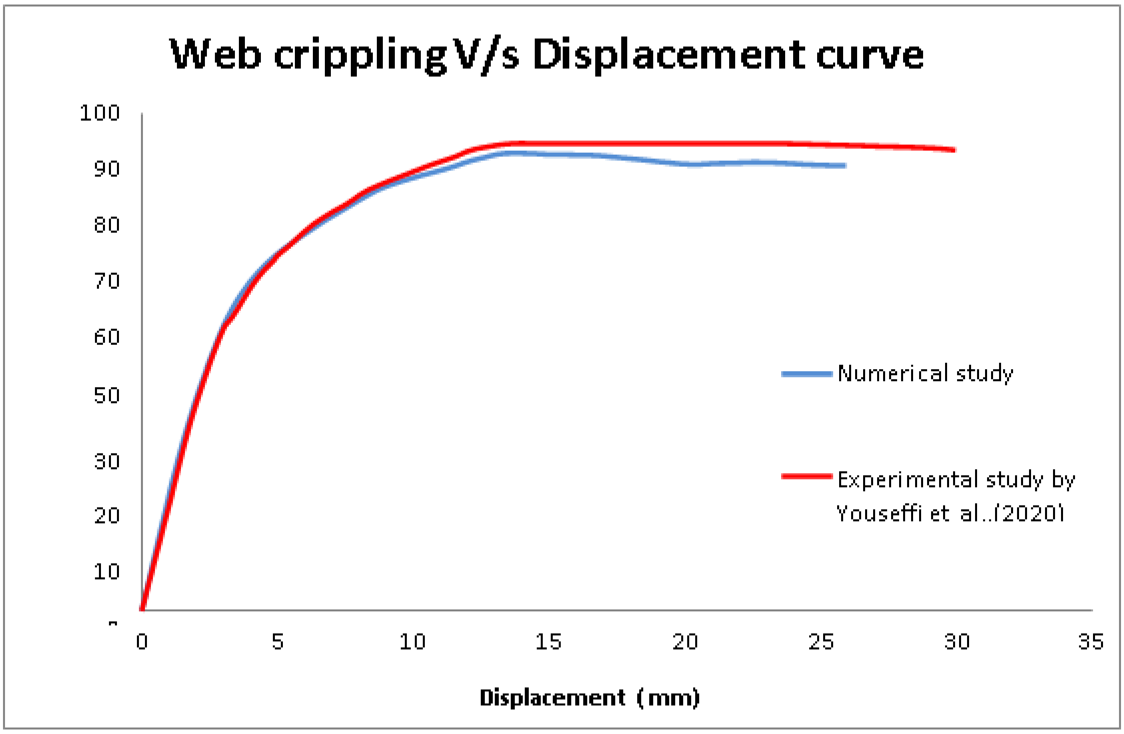

Fig 8. Web crippling strength V/s displacemnt comparison

From the above comparisons, the percentage variation of the finite element results from the actual test result was found to be within acceptable limits. The deformed shapes of the model from the finite element analysis and the tests results are shown above.

4. PARAMETRIC STUDY

4.1 Effect of variation of yield strength

Numerical study was conducted on ninety specimens with different cross sections of varying lengths. For all the specimens the bearing length was fixed as 50 mm and the inside bent radius ratio was fixed unity.

The influence of yield strength on web crippling strength and combined effect of bending and web crippling strength is graphically represented in figure. For both kinds of strengths the variation shows linear behaviour. Also the web crippling strength was found to be more than the combined bending and crippling strength for specimens having same cross section. The slope of the graph is found increasing as the thickness of the section increases. For all the specimens, three different thicknesses were also considered.

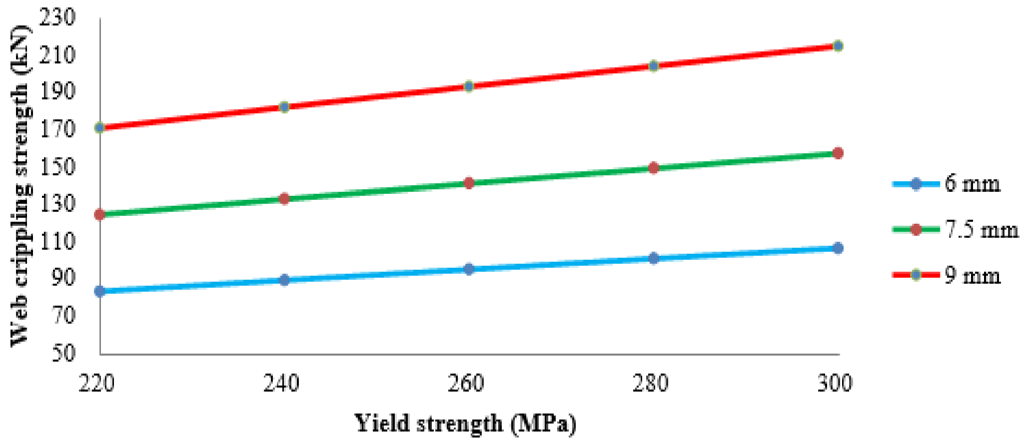

Fig 9. Variation of web crippling strength with yield strength for 130x65 sample

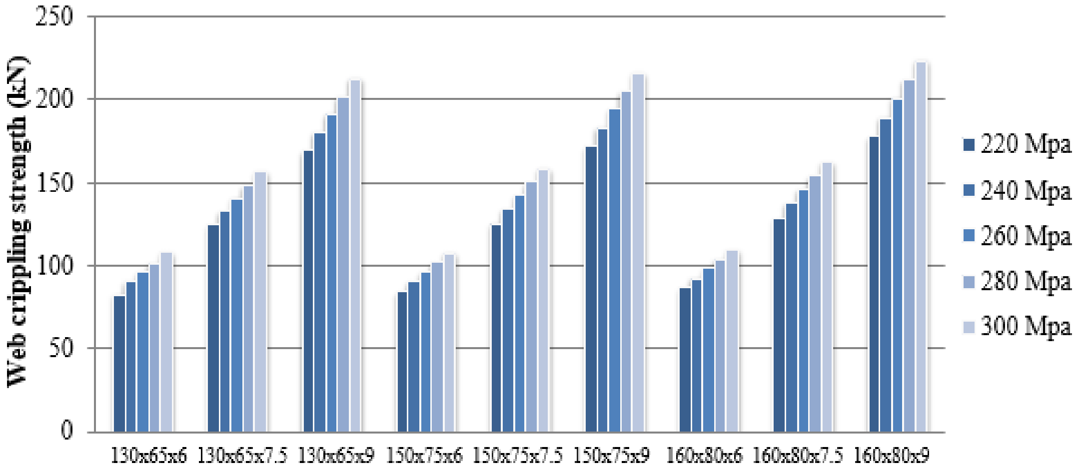

Fig 10 Variation of web crippling strength with yield strength for 600 mm length samples

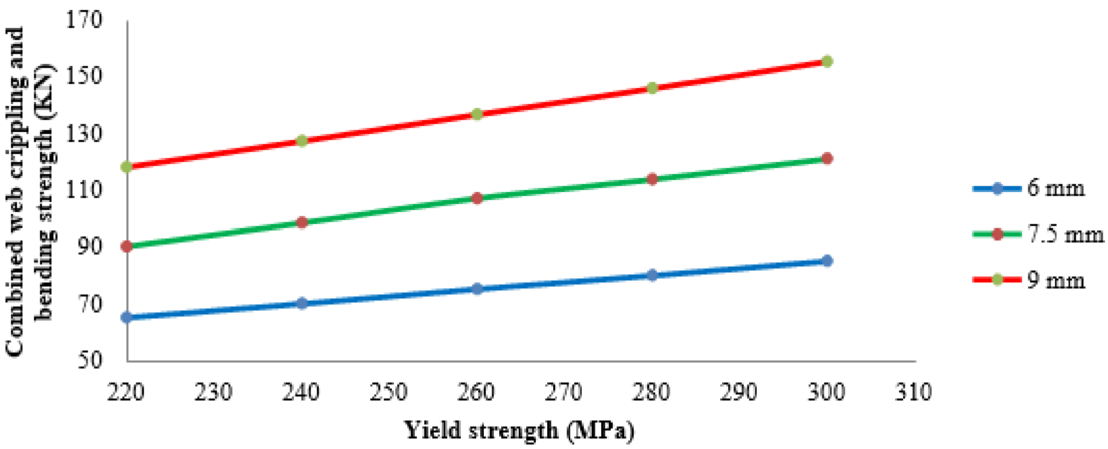

Fig 11. Variation of combined web crippling and bending strength with yield strength 130x65 sample

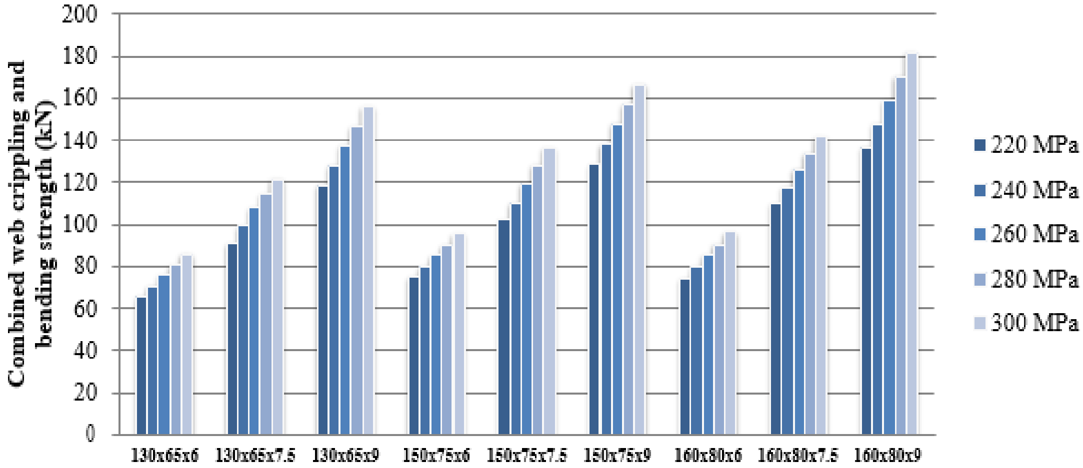

Fig 12. Variation of combined web crippling and bending strength with yield Strength 1000 mm sample

4.2. Effect of variation of inside bent radius

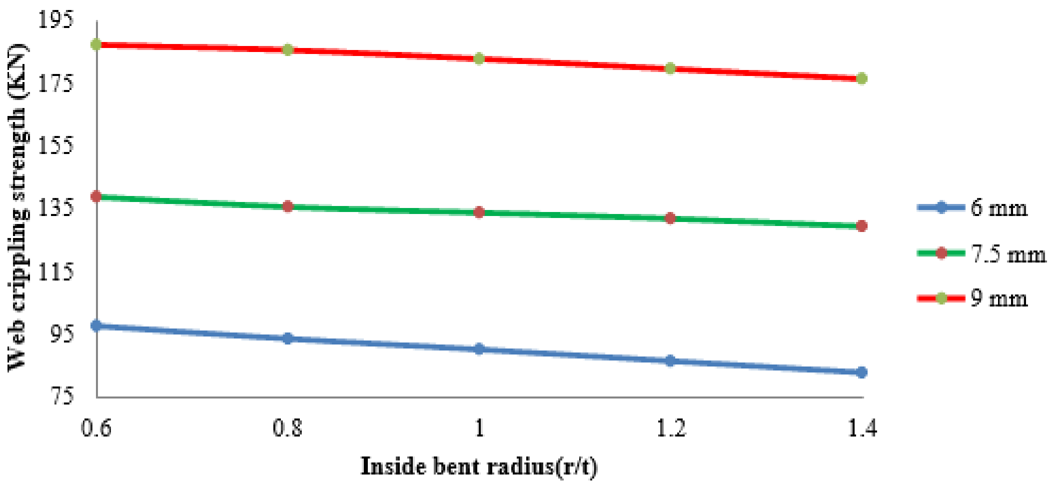

Fig 13. Variation of web crippling strength with inside bend radius for 130x65 sample

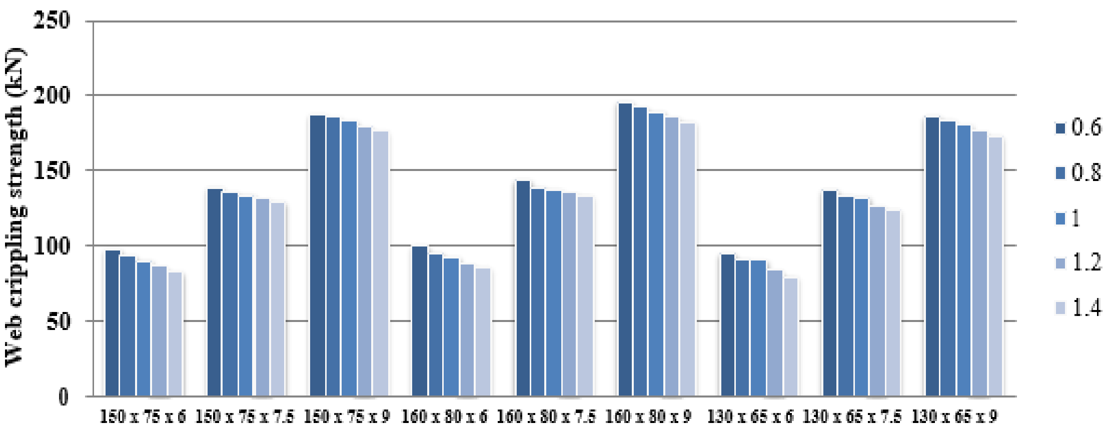

Fig 14. Variation of web crippling strength with inside bend radius for 600 mm samples

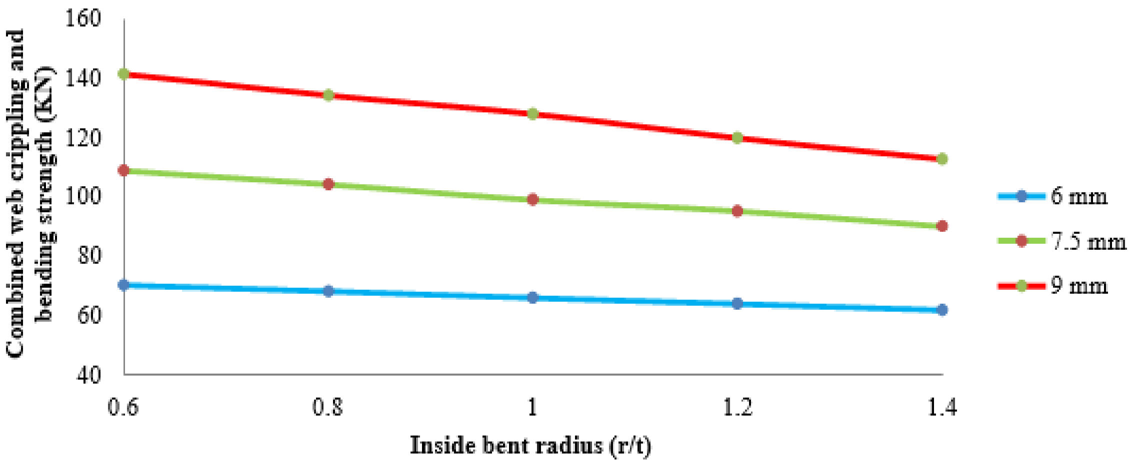

Fig 15. Variation of combined web crippling and bending strength with inside bend radius for 130x65 sample

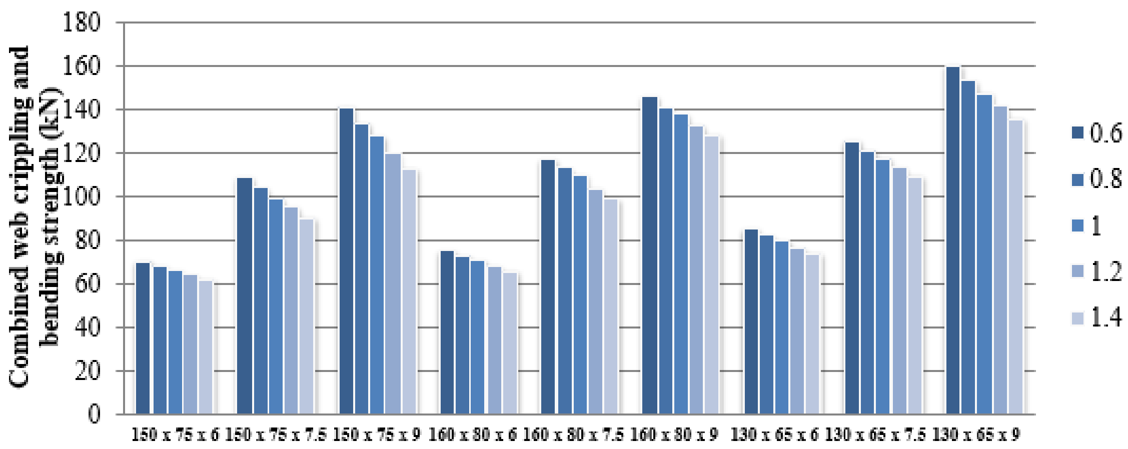

Fig 16. Variation of combined web crippling and bending strength with inside bend radius for 1000 mm samples

The variation in inside bent radius was achieved by varying the ratio of inside bent radius to thickness (r/t). The linear varying trend was observed for both web crippling as well as combined bending and crippling strengths. Apart from the increasing trend by yield strength, the inside bent radii exhibit negative slopes. In all cases the web crippling strength was the dominant. The strength decreased by an average of about 5% for an increase of r/t ratio by 0.2. The strength was found to be decreasing at higher rate for the specimens with high thicknesses.

4.3. Effect of variation of section thickness

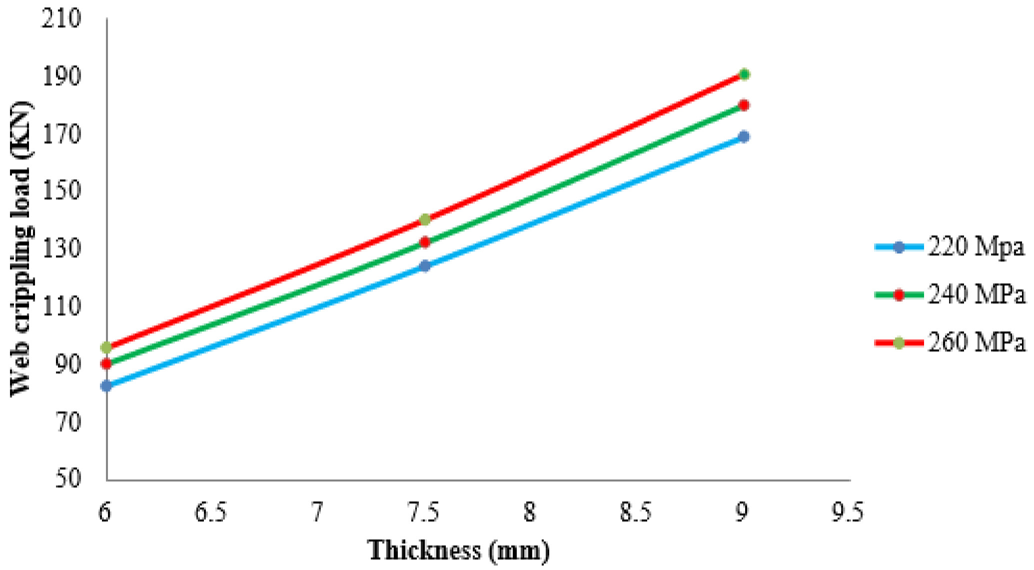

Fig 17. Variation of web crippling strength with thickness for 130x65 sample

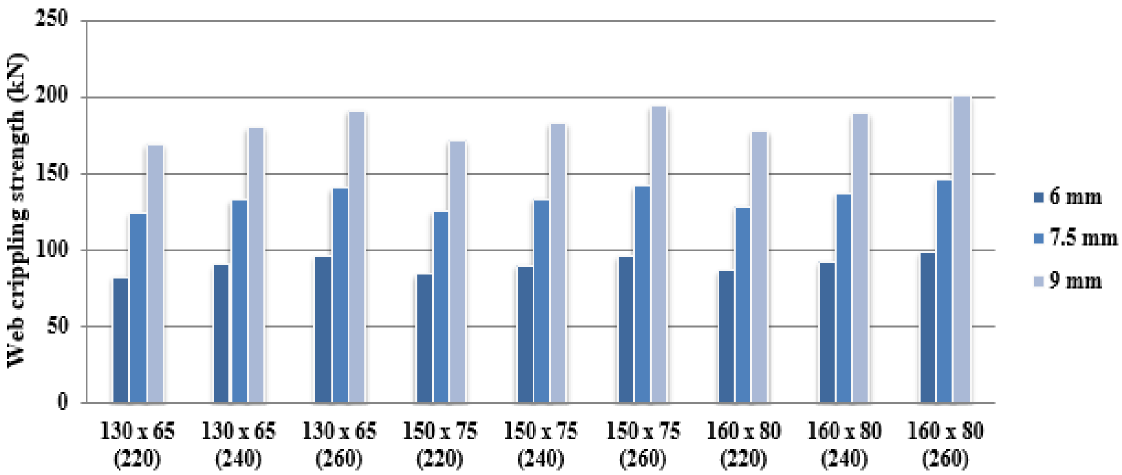

Fig 18. Variation of web crippling strength with thickness radius for 600 mm samples

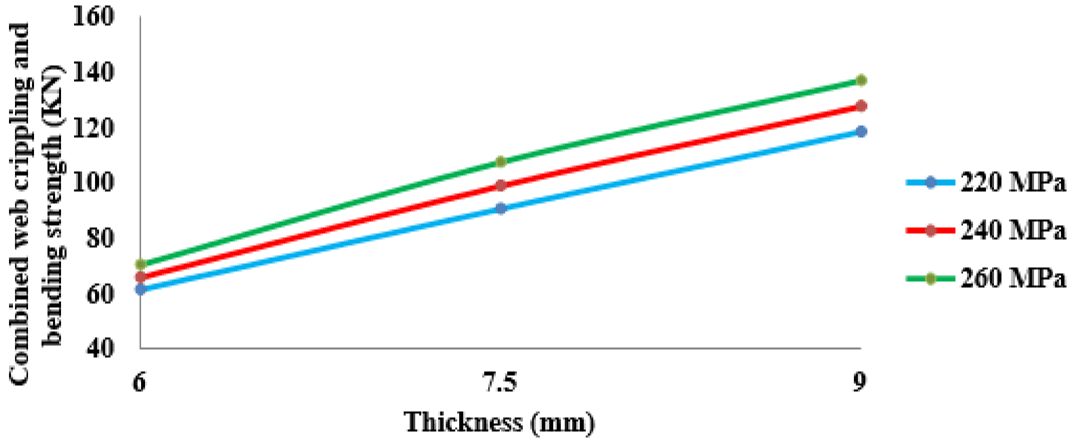

Fig 19. Variation of combined web crippling and bending strength with thickness for 130x65 sample

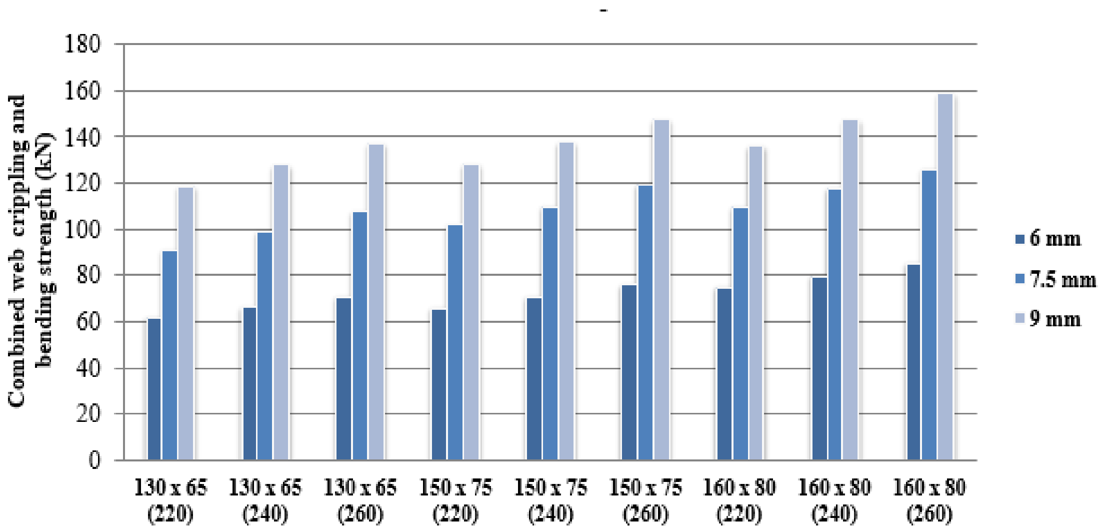

Fig 20. Variation of combined web crippling and bending strength with thickness for 1000 mm samples

Thickness is the parameter observed with more influence on web crippling and combined effect of crippling and bending. For all specimens the web crippling strength dominates over combined strength. On an average increase of 20 % in the thickness of the section, web crippling strength as well as the combined strengths had an increment of 35%.

4.4. Effect of variation of bearing length

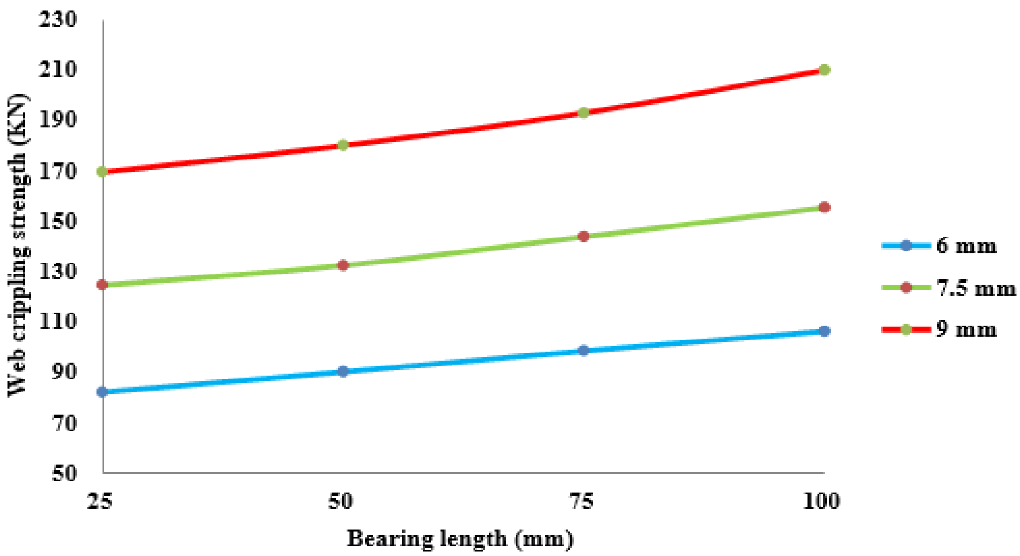

Fig 21. Variation of web crippling strength with bearing length for 600 mm samples

The effect of web crippling strength with the variation of bearing length was observed linear. In all the cases the specimens with highest bearing length shows the highest web crippling strength. For every 25 mm increment in the bearing length the web crippling capacity increased by 10%. The variations of strength with bearing length of all specimens were graphically represented below.

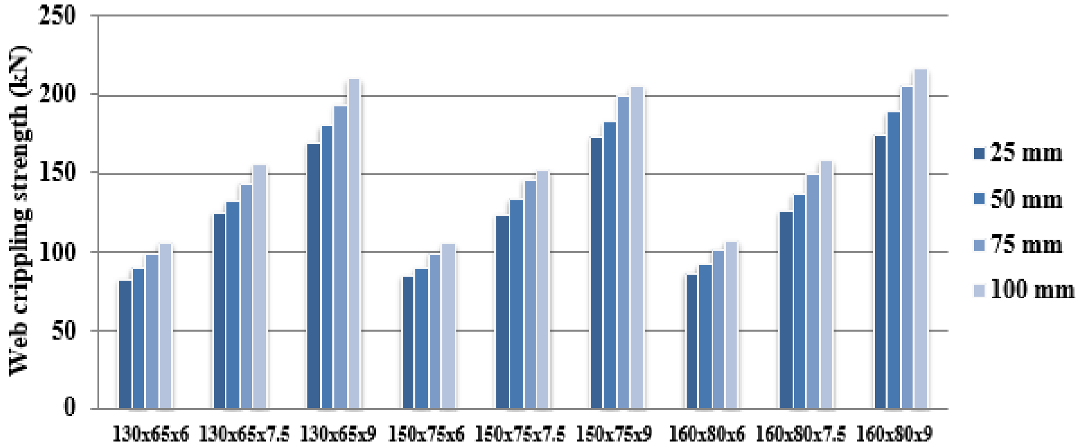

Fig 22. Variation of combined web crippling and bending strength with thickness for 600 mm samples.

5. CONCLUSIONS

From the study, it was found that web crippling strength and combined bending and web crippling strength of austenitic stainless steel channel sections under interior one flange loading condition varies linearly with the variations of yield strength. It was observed that the combined bending and crippling strength is lower than the web crippling strength. In both failure cases, an increase of 6-7% observed in strength for an increase of yield strength by 20 MPa.

The effect of variation of web crippling strength and combined bending and crippling strength with inside bent radius was observed linear. Both the strengths decreased by the increase of inside bent radius. This effect is more prominent for the sections with higher section thicknesses and can be due to the presence of eccentricity caused by the inside radius leading to an additional moment generated.

From the parametric study, it was observed that thickness is the highest influential parameter. All the design codes as well as numerical study exhibit almost straight line variations. On an average increase of 20 % in the thickness of the section, web crippling strength as well as the combined strengths had an increment of 35%.

As per the parametric study, the web crippling strength increases as the bearing length increases. For an increase of 25 mm of bearing length, web crippling strength increased by an average of 10%.

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