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Determination of Buckling limit diagram for metal sheets

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Abstract:

Sheet buckling a form of instability, is undesirable in final products as it contributes a decrease in part stiffness and affects part appearance and assembly. Controllable local buckling is sometimes introduced in forming processes to bring additional material to a forming cavity for subsequent stretching, which results in a more complex or deeper part. In this paper, the buckling limit diagrams (BLDs) were experimentally evaluated for mild steel and stainless steel SS316 sheets with thickness (1mm). The highest resistance of buckling in the buckling limit diagram is found in the stainless steel SS316 sheet and the lowest resistance in the mild steel sheet , also we can find the maximum buckling height in specimen 3 (50mm) of mild steel sheet , and the lowest buckling height shown in specimen 1 (18mm) for stainless steel SS316 sheet. The maximum elongation shown in specimen 1 (40) of mild steel sheet, and also the maximum load applied found in stainless steel SS316 sheet(60KN).

Keywords: Buckling limit diagram, Uniaxial Tension Forming, Buckling Height.

تعيين مخطط حد الانبعاج للصفائح المعدنية

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الخلاصة :

يعتبر الانبعاج في الصفائح المعدنية شكل غير نظامي وغير مرغوب فيه عند المنتج النهائي مما تساهم في تقليل ثبات القطعة وتأثيرها في التجميع . والسيطرة على الانبعاج هي من العمليات المتقدمة في عمليات التشكل لما تحدثه من فراغات متتالية نتيجة التشكيل بالمط وخاصة في الاشكال المعقدة والسحب العميق . في هذا البحث تم تعيين مخطط حد الانبعاج عمليا لكل من صفائح الصلب المطيلي والصلب المقاوم للصدأ (SS316) ذات سمك 1ملم . وقد وجد أن أعظم مقاومة للانبعاج في مخطط حد الانبعاج في صفيحة من الصلب المقاوم للصدأ (SS316) واقل مقاومة في صفيحة الصلب المطيلي. كذلك وجد أن أعظم ارتفاع للانبعاج ظهر في النموذج الثالث (50 ملم) لصفيحة من الصلب المطيلي ، واقل ارتفاع للانبعاج ظهر في النموذج الأول (18ملم) لصفيحة من الصلب المقاوم للصدأ. وجد ان اعظم استطالة حدثت في النموذج الاول (40) في صفيحة الصلب المطيلي وكذلك وجد ان اعظم حمل مسلط في صفيحة من الصلب المقاوم للصدأ (SS316)(60 ك نت) .

Notation:

e_1, e_2, e_3	Principle strains.
n	Strain hardening exponent.
K	Strength coefficient.

1.Introduction:

Buckling and tearing are some of the common instabilities that can develop during sheet–metal forming. Sheet tearing is the most common and important instability that can be observed under stretching conditions and usually takes place in regions that have thinned locally, i.e. in localized necks. So, buckling is a typical defect in sheet metal forming and depends on the wear of the tool.[1]

The buckling phenomenon (initiation and growth) depends on many factors such as mechanical properties of the sheet, geometry of the work piece, stress ratios, contact condition, etc. So, it is difficult to analyze the buckling behavior considering all the factors because of their complexity and the buckling behavior may show a wide dispersion of data even for small deviations of factors. [2]

They investigated the buckling phenomena of plates and studied the effect of blank holding force upon buckling initiation and number of buckling waves quantitatively. Simple analytical bifurcation analysis can give a useful estimate of elastic–plastic buckling when the sheet has an elementary shape and is subject to boundary conditions that are easily prescribed. [3-4]

There are two types of buckling analysis using the finite element method; the bifurcation analysis of perfect structure and the nonbifurcation analysis employing initial imperfection.[5-6] A modified Yoshida buckling test is presented as an improved and more reliable buckling test in order to determine the buckling limit diagrams (BLDs) of IFS when ranking the formability of sheet metals. The finite element analysis (FEA) is carried out for the modified Yoshida buckling test and compared with the experimental results [7]**.** With all the work in numerical predictions, it is necessary to have well controlled experiments to verify numerical approaches. The experimental work on studying the buckling formation and its decisive factors can be divided into two categories. One approach includes simple tests of special specimens designed for simulating the basic mechanism in sheet metal forming, such as the Yoshida Buckling test .[8]

A wedge strip test is designed to study the onset and post-buckling behavior of a sheet under various boundary constraints.[9] The device can be easily incorporated into a conventional tensile test machine and material resistance to buckling is measured as the buckling height versus the in-plane strain state.[9]

The aim of this work is to determine the buckling limit diagram for all sheets (steel, aluminum and stainless steel SS316) and compare with all , and also determine the buckling height for all sheets.

2.Experimental Procedure :

2.1 Chemical Composition:

The chemical composition for all sheets are shown in tables(1) and (2).

Table (1) Chemical Composition for Mild Steel sheet in Wt%

Material (thick.)	**Mo%**	**Ni%**	**Cr%**	**S%**	**P%**	**Si%**	**Mn%**	**C%**	**Fe%**
Mild Steel (1 mm)	0.007	0.03	0.04	0.011	0.004	0.022	0.1	0.08	Rem.

Table (2) Chemical Composition for Stainless Steel SS316 sheet in Wt%

Material (thick.)	**Mo%**	**Ni%**	**Cr%**	**S%**	**P%**	**Si%**	**Mn%**	**C%**	**Fe%**
SS316 (1 mm)	2.4	11.3	16.5	0.011	0.004	0.5	1.4	0.06	Rem.

2.2 Mechanical Properties:

The mechanical properties of sheets metals were obtained from tensile test table (3).[10] By using specimens at different angles (0°, 45°, 90°) to the rolling direction. After testing,

Table (3) Mechanical Properties for all sheets

Material	**Thickness (mm)**	**0.2%Proof stress (MPa)**	**Ultimate stress (MPa)**	**Total Elongation(%)**
Mild Steel	1	180	365	40
Stainless steel SS316	1	200	510	30

The value of strain hardening exponent (n) was determined from the slope of line in the (log coordinate of true stress-strain curve) by selection two points one before ultimate stress and the other after yield point. The intersection of this line with unit strain gives the stress value that define the magnitude of strength coefficient (K) (table 4) .[10]

Table (4) Strain Hardening exponent and Strength Coefficient.

Material (thick.)	**Mean of Strain Hardening exponent (n)**	**Mean of Strength Coefficient (K) [Mpa]**
Mild Steel (1 mm)	0.322	650
Stainless steel (1 mm)	0.4	950

2.3 Specimens of Buckling test :

Using three type of specimens in buckling with equal length (300 mm) and having various widths on octagon shape (Fig.1.A). the specimens represent the region of buckling limit, figure (1.B) show image of specimens.

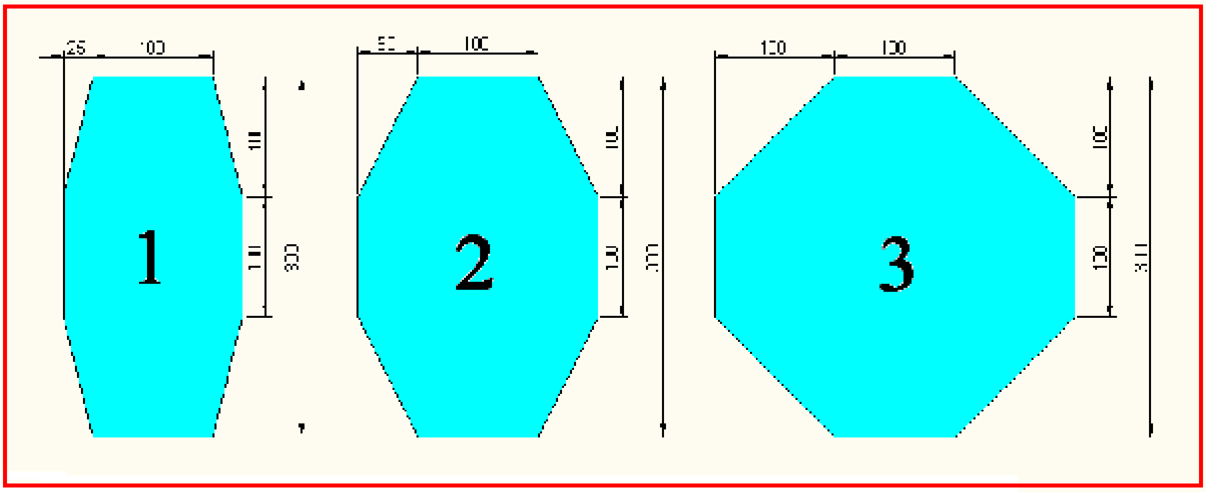

Fig.(1.A) Shape of specimens using in buckling

Fig.(1.B) Image of specimens using in buckling

2.4 Draw the net of circle grid over surface sheet:

Draw the net of circle grid (5 mm diameter) on the surface of the specimens for the purpose of strain measurements using special pin , this method is more active and simple to draw on the sheet surface.

2.5 Uniaxial tension of specimens and measured strain:

After draw the net of circle grid, the specimens deform by using uniaxial tension test, the shape of circles in the net are change to ellipse shape after deformation **Figure(2).**Using measurement tap to measure the major and minor diameter in ellipse. The relationships (1) and (2) using to measure major and minor strain.

$$e_1 = \ln \frac{d_1}{d_0} \qquad (1)$$

$$e_2 = \ln \frac{d_2}{d_0} \qquad (2)$$

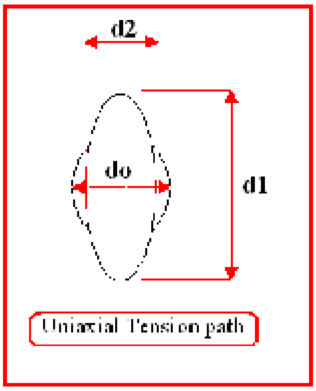

Fig.(2) circle before and after forming

3. Results and Discussion :

Figure(3) Shows the relationship between buckling height and elongation of stainless steel SS316 sheet for all specimens, It can be seen from comparison that the maximum buckling height shown in specimen 3 (45mm) with lower elongation and the lowest buckling height shown in specimen 1 (16mm) with high elongation(38).

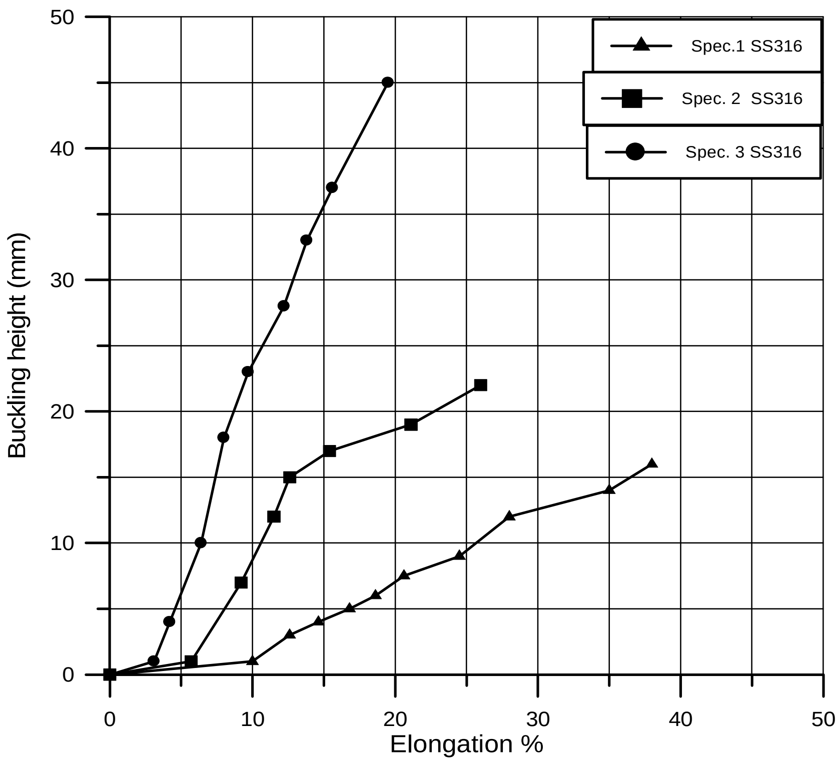

Fig.(3) Buckling height and elongation for stainless steel SS316 sheet

Figure(4) Shows the relationship between buckling height and load supplied of stainless steel SS316 sheet for all specimens, It can be seen from comparison that the maximum buckling height shown in specimen 3 (45mm) at load (60 KN) and the lowest buckling height shown in specimen 1 (16mm) at same load(60 KN) .

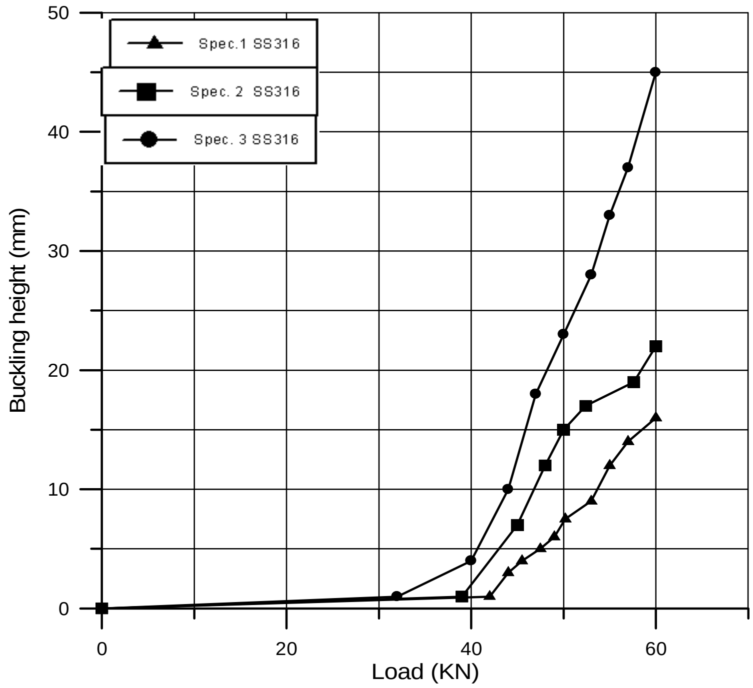

Fig.(4) Buckling height and load for stainless steel SS316 sheet

Figure(5) Shows the relationship between buckling height and elongation of mild steel sheet for all specimens, It can be seen from comparison that the maximum buckling height shown in specimen 3 (50mm) with lower elongation, and the lowest buckling height shown in specimen 1 (20mm) with high elongation(40).

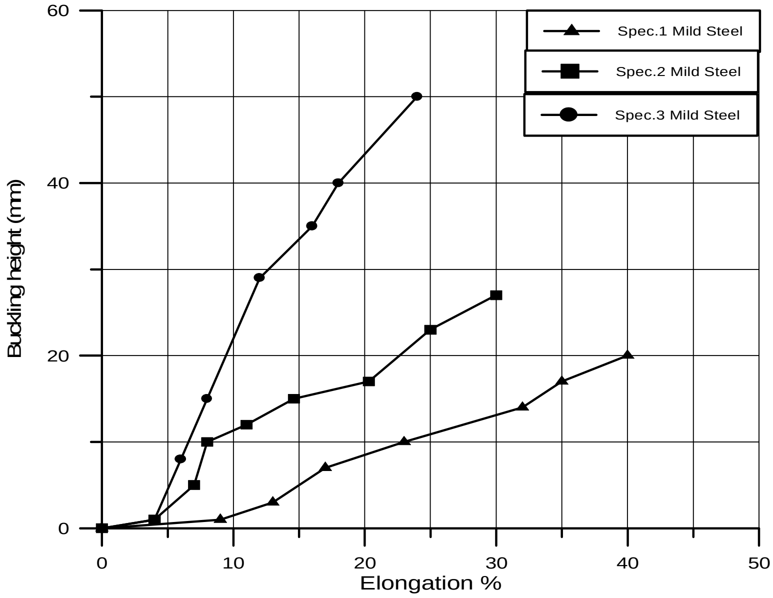

Fig.(5) Buckling height and elongation for mild steel sheet

Figure(6) Shows the relationship between buckling height and load supplied of mild steel sheet for all specimens, It can be seen from comparison that the maximum buckling height shown in specimen 3 (50mm) at load (53KN)and the lowest buckling height shown in specimen 1 (20mm) at same load(53KN) .

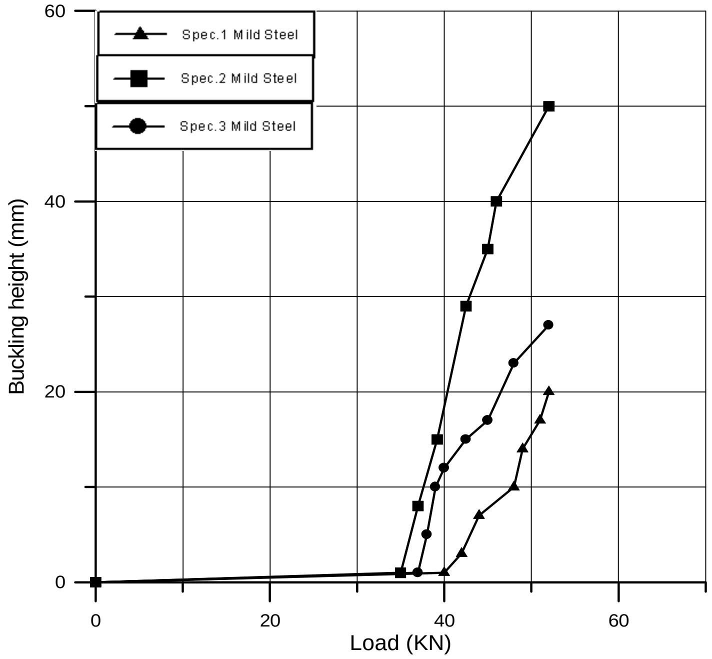

Fig.(6) Buckling height and load for mild steel sheet

Figure(7) shows the comparison between stainless steel SS316 and mild steel sheets for buckling height and elongation. It can be seen from comparison that the maximum buckling height shown in specimen 3 (50mm) of mild steel ,with lower elongation in specimen 3(19) for stainless steel SS316, and the lowest buckling height shown in specimen 1 (18mm) for stainless steel SS316 .

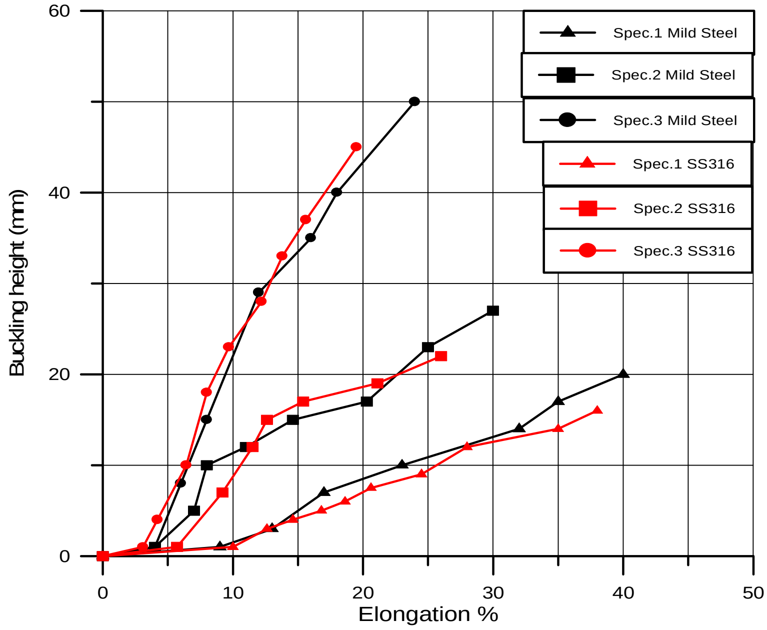

Fig.(7) comparison between stainless steel SS316 and mild steel sheets

Figure(8) shows the buckling limit in buckling limit curves for mild steel and stainless steel SS316 sheets , It can be seen from comparison that the maximum resistance of buckling shown in SS316 and lower resistance in mild steel. **Figure(9)** shows image of specimen after deformation.

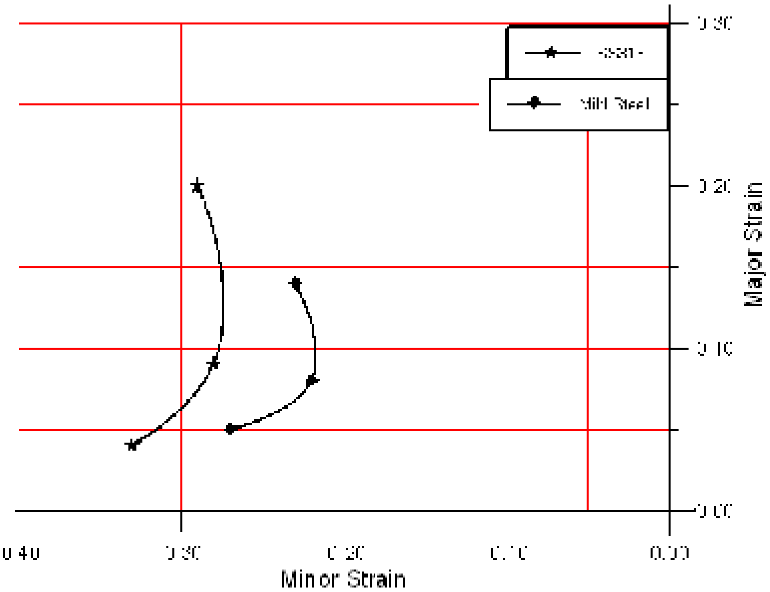

Fig.(8) Buckling limit diagram for SS316 and mild steel sheets

Fig.(9) Image of specimen after deformation of buckling

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