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Plastic buckling of Metallic and Nonmetallic Thin-Walled Tubes under Static Axial Compression

Ayad Aied Mahuof Albadrany
Department of Mechanical Engineering- AlAnbar University

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Abstract

An experimental study for series of tests were conducted on stainless steel 304 and polyvinylchloride circular tubes loaded statically and axially at room temperature. The specimens tested with same variation of slenderness ratio for both materials with constant axial length. Load-deflection characteristics for stainless steel 304 and polyvinylchloride circular tubes specimens and the influence of plastic properties and collapsing load were illustrated .The experimental results are compared with other experimental published and give good agreement. It is showed that the values of initial peak load ,yield end load and plastic work increase with increasing slenderness ratio at constant length. Also it is observed that the collapse modes are different for both materials.

Key words: Compression of shells, axial collapse, plastic work of shells.

الانبعاج اللدن للأنابيب المعدنية واللامعدنية الرقيقة تحت الضغط المحوري الساكن

الخلاصة

دراسة تجريبية لنوعين من المواد المعدنية (stainless steel 304) واللامعدنية (PVC) ذات مقاطع أنبوبية دائرية تحت ضغط ساكن .سلسلة من الاختبارات أجريت على كلا المادتين من الأنابيب الدائرية الرقيقة حملت تحميلا استاتيكيا ومحوريا عند طول ثابت و نسبة قصافة متساوية لكلا المقطعين وبدرجة حرارة الغرفة.

خواص الانهيار والمتمثلة بحمل الانبعاج والاختزال الطولي للنماذج المعدنية واللامعدنية تم عرضها في هذه الدراسة.

تم مقارنة النتائج العملية لكلا المادتين بنتائج تجريبية سابقة وكانت قريبة جدا من النتائج التجريبية للعمل الحالي.

تم التوصل في هذه الدراسة أن قيمة الحمل الابتدائي الأقصى والحمل النهائي والشغل اللدن يزداد بزيادة نسبة القصافة لكلا المادتين.كذلك تم مقارنة مراحل التشوه اللدنة لكلا النموذجين إلى مرحلة الفشل وقد تبين أن أسلوب التشوه للنماذج المعدنية ذات المقطع الدائري يختلف عن النماذج اللامعدنية لنفس المقطع.

الكلمات الدالة: الرقائق المضغوطة، الانهيار المحوري، الشغل اللدن للرقائق.

Notations

Dm mean diameter of tube
L axial length of tube
t wall thickness of tube
Pmax experimental initial peak load
Py yield end load
P experimental mean buckling load
σy yield stress
W experimental plastic work
δ reduction in axial length

Introduction

Experimental studies give much attention to the behavior of relatively thin wall structural components under static or dynamic axial load for their use as efficient energy absorbing devices.[1-3]

Crumpling mechanisms for such devices using the concepts of stationary and traveling plastic hinges for calculating the buckling force and a mount of plastic work have been proposed. [4-6]

Several experimental, analytical and numerical studies have appeared in recent years, which help in understanding of plastic mechanics of collapse phenomenon.

Experimental studies on metallic tubes and nonmetallic tubes have shown that the mode of deformation and buckling force depend on geometrical dimensions and material properties.[7-10]

Circular hollow steel tubes are widely used as columns in many structural systems and a common failure mode of such tubes when subjected to axial compression and bending is local buckling near a column end. For example, hollow steel tubes are often used as bridge piers and such bridge piers suffered extensive damage and even collapses during the 1995 Hyogoken-nanbu earthquake[11]

A number of methods have been proposed for the seismic retrofit of hollow steel tubes as bridge piers where enhancement of ductility without a significant strength increase is preferred, but each method suffers from some limitations.[12]

In the present work , stainless steel 304 and PVC circular tubes specimens loaded statically to study the effect of slenderness ratio(wall thickness/mean diameter) and material properties on initial peak load, yield end load and work done(plastic work) by axial compression of material by assuming rigid-perfectly plastic material. The experimental results compared with previous experimental researches.

Experimental Work and Results

The axial compression of stainless steel 304 and PVC circular tubes was carried out by compression universal test machine, these materials wide used in engineering applications such as civil and environment of engineering and most application of mechanical engineering. The initial value of yield stress of stainless steel 304 and PVC was estimated by static tensile test to be 0.384 $kN.mm^{-2}$ and 0.050 $kN.mm^{-2}$ respectively, which are the average of three readings.The compression tests of specimens carried out at a crosshead speed of 10mm/min or strain rate of (0.00130 sec^{-1}). Details relating to the geometrical dimensions of specimens are presented in Tables (1) and (2).Both the stainless steel 304 and PVC circular tubes specimens have the same slenderness ratio(wall thickness/mean diameter), which is varied with range ($0.015\leq$ t/Dm ≤ 0.047). All specimens were tested at constant temperature.

The variation of axial crumpling load with shortening of the axial length of all specimens at failure were obtained using autographic recorder as shown in Figs(1-8).

The shape of plastic deformation for specimens at complete reduction in axial length(δ) are illustrated in Figs (12a)and(12b).

The values of initial peak load (Pmax), mean load (P) and work done (W) by plastic deformation for both materials are calculated from the experimental load–deflection curve. The values of yield end load calculated from equation Py= $\sigma y.\pi t.Dm.$ [4], as shown in Tables(1) and (2).The experimental plastic work (W) equal the energy dissipated by deformation of material and equal the area of load–deflection curve.The value of mean load(P) equal the plastic work divided on deflection(δ).The value of the reduction of axial length at failure for all specimens test equal (83 mm).

Discussion and Conclusions

The compression process are presented by initial peak load, yield end load ,mean load and plastic work calculated from the load-deflection curves of specimens by assuming rigid-perfectly plastic material. Tables(1) and (2) show the values of initial peak load, yield end load ,mean load and plastic work for stainless steel 304 and PVC circular tubes respectively, these results gave good a agreement with previous experimental results in researches.[4,5,13]

The Figs (9) and (10) show that the values of initial peak load and yield end load increase with increasing slenderness ratio for both specimens stainless steel 304 and PVC circular tubes .The values of initial peak load and yield end load of stainless steel 304 circular tubes more than PVC circular tubes because the buckling load effect by the material properties, such as yield stress, [4]. Also the slope (fit curve) of the stainless steel 304 more than the slope (fit curve) of PVC circular because the metallic tubes have high strength but the nonmetallic tubes have low strength. The values of initial peak load and yield end load of stainless steel 304 for present work gave good agreement comparison with data of low-carbon steel CR 1018, [13] all one the data of PVC compared with data of PVC in research,[5] and gave good agreement with present data.

The columns 10 in Tables (1) and (2) show that the ratio between the initial peak load and mean load more than one for both circular tubes specimens with variation the slenderness ratio and compared with ratio previous data of researches in column 11 in Tables (1) and(2), and gave close results as compared with experimental data [5,13].

The difference of the results in Table(1) and Table(2) in column 11 with column 10 because the geometrical shape of deformation through the compression process is a significant factor affecting the average load.[2,5]

The Fig (11) and column 8 in Tables (1) and (2) illustrate that the values of plastic work and average load for both circular tubes specimens increase with increasing the slenderness ratio respectively, [5,13].The value of plastic work and average load of stainless steel 304 large than PVC circular tubes at the same slenderness ratio because the collapse modes depend on material properties. [4]

A comparison between the already discussed collapse modes of stainless steel 304 and low-carbon steel CR 1018 circular tubes[13], indicated that are similar. Also the collapse modes of PVC for present work as the same collapse modes of PVC in research[5],but the collapse modes of stainless steel 304 and PVC circular tubes are different as shown in Fig(12a) and (12b), because the deformation depends on the types of material and mechanical properties, such as stiffness where the plastic materials have low stiffness but the metals have high stiffness. [5,9,11]

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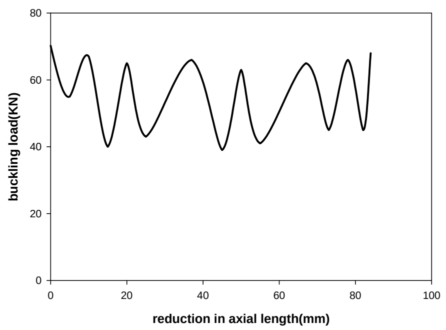
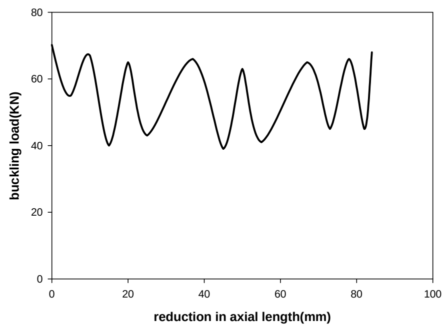
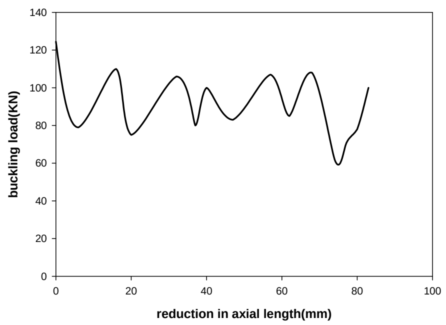


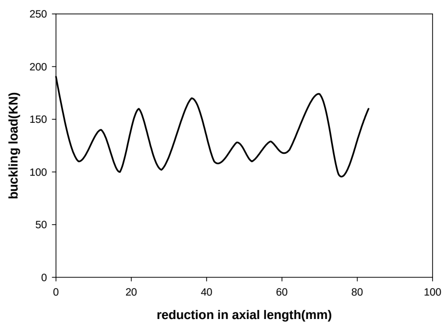
Fig(1): Load-deflection curves for stainless steel 304 circular tube specimen(1)



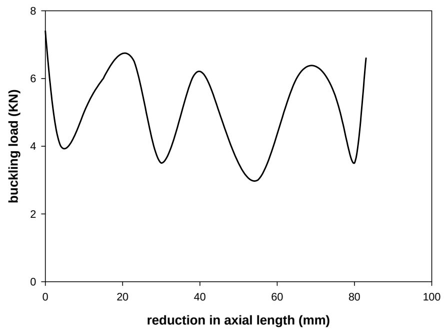
Fig(2):Load-deflection curves for stainless steel 304 circular tube specimen(2).



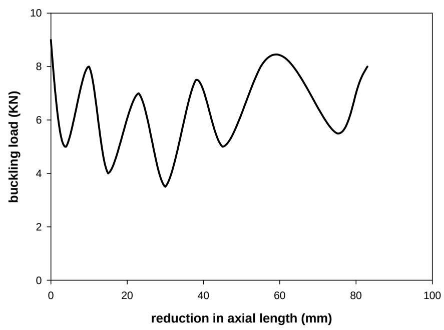
Fig(3):Load-deflection curves for stainless steel 304 circular tube specimen(3).



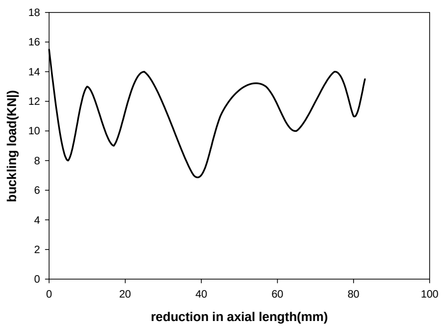
Fig(4): Load-deflection curves for stainless steel 304 circular tube specimen(4).



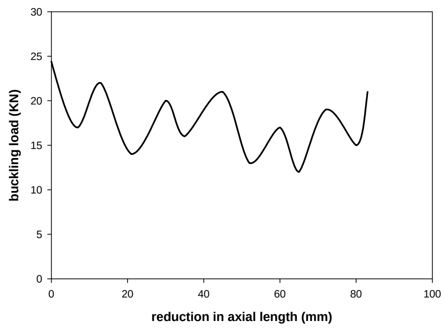
Fig(5): Load-deflection curves for PVC circular tube specimen(1).



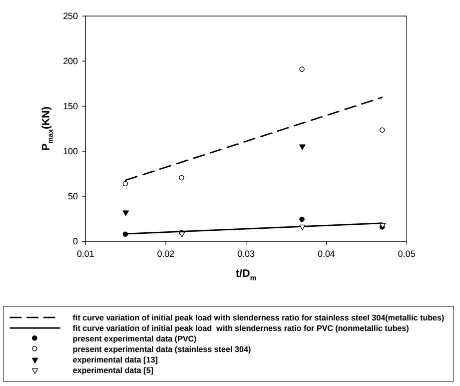
Fig(6): Load-deflection curves for PVC circular tube specimen(2).



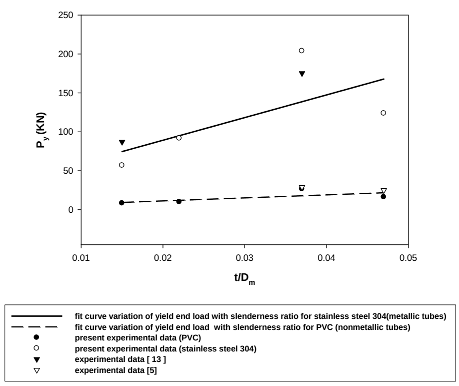
Fig(7): Load-deflection curves for PVC circular tube specimen(3).



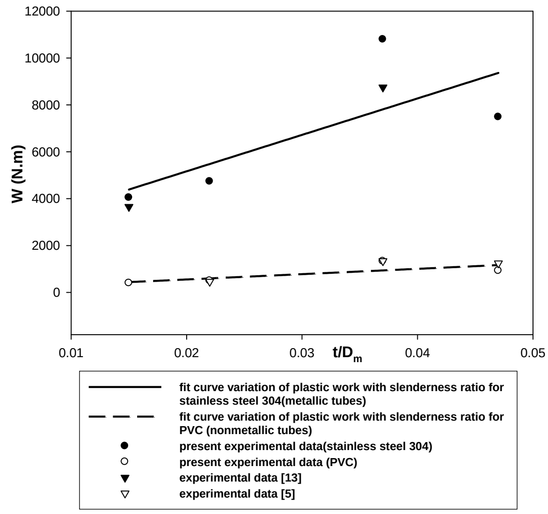
Fig(8): Load-deflection curves for PVC circular tube specimen(4).



Fig(9):Variation of initial peak load with slenderness ratio.



Fig(10):Variation of yield end load with slenderness ratio.



Fig(11):Variation of plastic work with slenderness ratio.

(a)

(b)

Fig(12):(a)The stages of deformation modes at failure for stainless steel 304 tube.
(b) The stages of deformation modes at failure (complete deflection) for PVC tube.

Table(1):The variation of static compression data on stainless steel 304 circular tubes

No of Specimen	Axial Length (L) (mm)	Mean diameter (D_m) (mm)	wall thickness (t) (mm)	ratio (t/D_m)	Experimental Initial peak load (P_{max})(KN)	Experimental Yield end load (Py)(KN)	Experimental mean load (P)(KN)	Experimental plastic work (W)(N.m)	Experimental ratio (P_{max}/p)	Mamalis and et al (P_{max}/p)
1	128	58.1	0.9	0.015	63.37	56.8	48.7	4042.1	1.3	-
2	128	52.8	1.2	0.022	70	91.7	57	4731	1.22	-
3	128	46.8	2.19	0.047	123	123.7	90.1	7478.3	1.365	1.6
4	128	67.29	2.51	0.037	190.5	203.8	130	10790	1.465	1.65

Table(2):The variation of static compression data on PVC circular tubes

No of Specimen	Axial Length (L) (mm)	Mean diameter (D_m) (mm)	wall thickness (t) (mm)	ratio (t/D_m)	Experimental Initial peak load (P_{max})(KN)	Experimental Yield end load (Py)(KN)	Experimental mean load (P)(KN)	Experimental plastic work (W)(N.m)	Experimental ratio (P_{max}/p)	P.D.Soden and et al (P_{max}/p)
1	128	58.1	0.9	0.015	7.4	8.21	4.8	398.4	1.54	-
2	128	52.8	1.2	0.022	9.1	9.95	6	498	1.516	1.4
3	128	46.8	2.2	0.047	15.4	16.17	11.1	921.3	1.387	1.63
4	128	67.29	2.51	0.037	24	26.53	16	1328	1.5	1.3