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Experimental and Theoretical Investigation of Impact Dynamic Plasticity for CK45

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Abstract

The low velocity axial impact of thin-walled circular ck45 tubes is taken. The wrinkles develop progressively and the phenomenon is known as dynamic progressive buckling. In the present paper, experimental and theoretical studies on dynamic plastic buckling of circular cylindrical shells under axial impact are carried out by designing and building a device to study the behavior of ck45 under low speed impact (3.8-6.25)m/s. The work consists of experimental and theoretical (Abramowicz model) for the energy absorbers and dynamic load under different velocities. The results show that when the velocity of impact increases, the value of the dynamic crushing stress for ck45 will increase, also for elastoplastic collapse deformation, a tube initially goes through elastic deformation, then plastic deformation occurs, after that the tube goes through plastic collapse. As the force decreases, the displacement still increases. Abramowicz model for dynamic impact shows well coincide with discrepancy 45%. It can be indicated that the increasing in the velocity or kinetic energy leads to increase in the load in the practical part while it seems to be horizontally linear in the theoretical part.

Keywords: *Impact, dynamic plasticity, Abramowicz model, energy absorbers,CK45.*

1. Introduction

Thin wall circular cylindrical shells are used as energy absorbing device. The energy absorption can be represented by collapsing plastically of thin wall tube in axial compression that converted kinetic energy into plastic deformation energy in deformable solids. The energy absorption divided into energy absorbing by friction and by deformation of solids. The use of metal components as energy absorbers which permits large plastic strains without failure. Plastic deformation and specially plastic buckling of tubes is an effective mechanism by which energy can be dissipated [1]. When the circular thin tubes are subjected to axial impact at speed sufficient to cause a moderate amount of plastic deformation axisymmetric bucking occurs [2]. Alexander [3] developed theoretical analysis for axisymmetric crushing of thin– walled cylindrical shell subjected to axial loading and he was the first who presented a mathematical simulation of the crushing problem for tubular members and collapsing in the axisymmetric. Abramowitz and Jones [4] have improved the Alexander solution by introducing a correction for the effective strain rate. Gu et al [5] used the energy criterion to study the radial buckling of cylindrical shells. Murase and Jones [6] investigated some experiments on aluminum shells subjected to high- velocity impacts also registered progressive buckling. Abramowicz and Jones [7] showed that a variety of dynamic buckling response of axially loaded shells is caused by coupling of the inertia effect with the inelastic material properties. Recent development in axisymmetric buckling of circular cylindrical shells have generated the effects of stress wave propagation [8].

However, the type of buckling depends on the magnitude of the impact velocity and the value of the striking mass. High velocity impacts cause dynamic plastic buckling , while the same shell collapses progressively for low- velocity impacts. The initial dynamic response of a shell for a high-velocity impact is more complex than for progressive buckling, but the subsequent buckling behavior can be developed progressively with time. The behavior of a tube crushed axially between rigid plates depends on its parameters , the ratio of length to mean diameter (L/D) and the ratio of mean diameter to thickness (D/h) as well as properties of material (yield stress and strain rate) [9]. In the present work, the dynamic buckling of steel ck45 thin tube under quasi-static and impact load is investigated experimentally and theoretically.

2. The Practical Aspect

2.1. Metal Selection

Steel ck45 according to AISI is chosen. Its chemical analysis is indicated in Table-1- . The Chemical composition was conducted by ARL spectrometer.

The mechanical properties is measured by Instron1195 apparatus for ck45 as indicated in Table-2-.

Table 1,
Chemical composition of the used metal (ck45).

	C%	Mn%	P%	S%	Fe%
Measured value	0.42-0.5	0.6-0.9	≤0.04	0.05	98.5-98.98
Standard value	0.472	0.567	-	0.03	REM

Table 2,
Mechanical Properties of the used metal (ck45).

	σ_y [MPa]	σ_u [MPa]	E (GPa)	Elongation	Hardness Vickers
Measured value	685	655	229	12%	196
Standard value	515	610	209.5		190

2.2. Specimen Preparation

Circular section steel alloy (ck45) tubes were used. These tubes were cut to equal lengths by cutter machine. Fig.(1) shows the shape and dimensions of the specimens used in this study. The specimen dimensions are thickness (t) =1mm , inner diameter (D_{inner}) = 16 mm , length (L) = 30 mm according to the standard DIN2250. [4].

Fig. 1. Specimen dimension.

2.3. Impact Test Rig

An impact test rig was constructed to impact the specimens at different velocities. Fig.(2) shows the impact test rig. Theexperimental tests were conducted on drop hammer rig in Fig.(2) , this rig has mass 22.92 kg , the velocity of the dropping mass was measured experimentally by the test rig end compared within the calculated velocity using $V = \sqrt{2gH}$, where H is the height of the dropping mass , the discrepancy of the results was about 5% (H was taken from (0.75-2) m and g=9.81 m/sec^2).

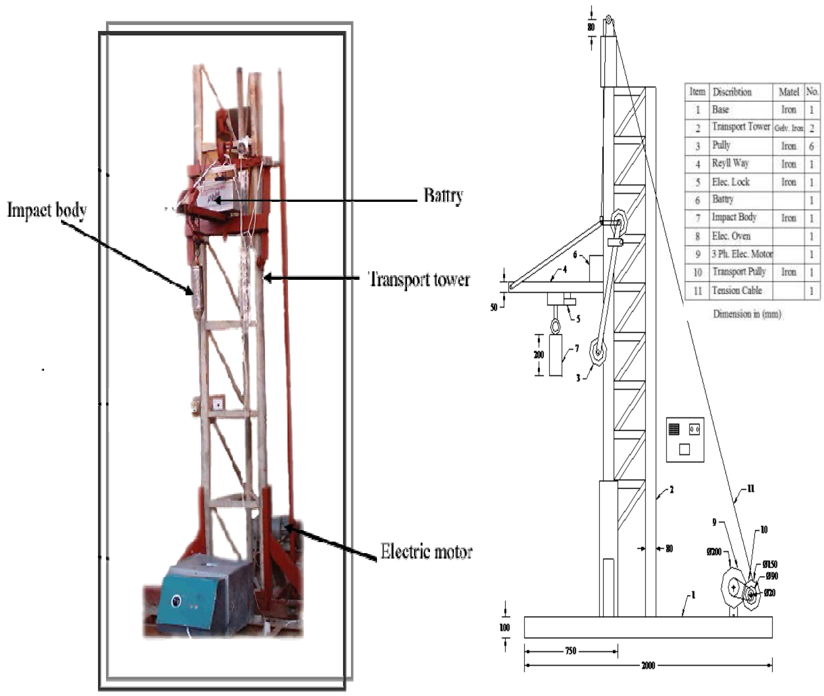

Fig. 2. Show the impact test rig.

2.4. Static Test (Compressive Test)

A load of 50 kN at 1mm/min speed was used as a compressive head. The aim of this test is to obtain the mode of deformation (concertina buckling). The results of the above test can be illustrated as in table(3), Fig.(3) shows the relationship between the stress and strain and Fig.(4) shows a specimen before and after testing. Fig.(5) shows a typical force- displacement curve for a tube crushed by a moving mass.

Table 3,
Results of static compressive tests for ck45.

P (kN)	δ mm	P (kN)	δ (mm)	P (kN)	δ (mm)
0	0	21.38	4.487	32.75	10.919
6.11	0.2992	23.414	5.08	21.719	11.219
15.27	0.5982	22.736	5.534	20.693	11.967
18.32	0.748	21.38	5.833	21.032	13.462
21.38	1.0472	19.337	6.731	19.676	14.359
24.43	1.1968	15.27	7.927	21.888	15.406
27.819	1.9448	22.736	8.975	21.38	15.706
25.786	2.244	23.75	9.27	20.693	16.454
21.38	2.8424	23.75	9.27	23.075	19.202
17.643	3.44	21.38	10.02		

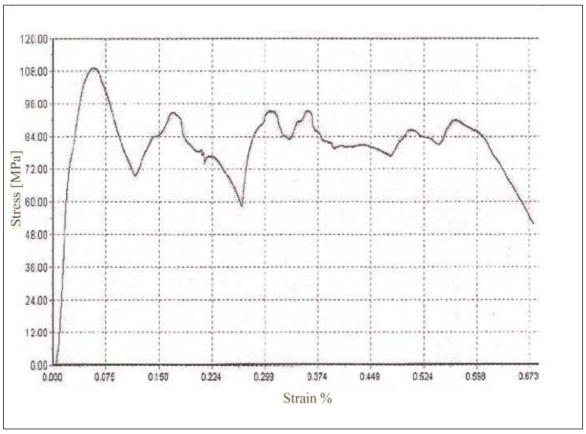

Fig. 3. A typical stress-strain curve for a tube crushed by a moving mass.

Fig. 4. Shows a specimen before and after testing.

Table (4) shows the mean load and energy absorbed by the specimen at failure with mode of deformation.

Table 4,
Static results at failure.

Failure	E_s(J)	ΔL_f (mm)	$P^m{}_f$ (kN)	Mode
Complete damage of specimen	422.8	19.334	21.868	Concertina buckling

The energy absorbed was calculated using the equation

$E_s=(Pm_{f}).(\Delta L_{f})$ …(1)

where :

ΔL_f : deformation at failure (mm)

Pm_f : mean load at failure (kN)

E_s: Energy absorbed by the specimen (Joule)

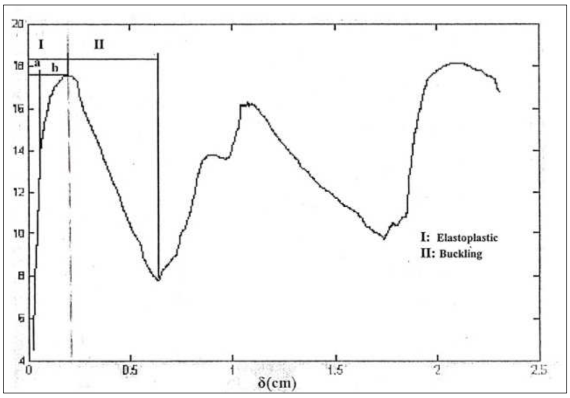

Fig. 5. Shows a typical force- displacement curve for a tube crushed by a moving mass.

Fig.(5) shows a typical force- displacement curve for a tube crushed by a moving mass. It is seen that tube initially goes through elastic deformation as shown in the range (a). This range behavior as the tensile or compressive test obeys to Hook's law. Then plastic deformation occurs as seen in range (b). After that, the tube goes through plastic collapse, as the force decreases while the displacement still increases range (II) in Fig.(5). This behavior shows approximately three folds when the first failure (folding) of the tube occurs. In an axial test, the tube gets crushed into several folds. After the first folding is finishes the second one occurs, then the third one. Due to the second folding, another elastoplastic deformation and plastic collapse occurs. The sequential deformations are repeated until the moving mass reaches its maximum displacement, unless a dramatic column buckling mode during the crushing test, this behavior of the metal used is impolitely coincide with the work of references [10] and [11]. Fig.(3) represented the energy absorbing capability of the impact limiter is controlled by several factors such as energy absorbing capacity, mean crush load, maximum crush load, crush load amplitude, etc. The impact energy absorber should be evaluated for some typical aspects collapse load, energy absorption, and collapse space efficiency.

2.5. Impact Test

Ten specimen are tested at different speeds (3.834 – 6.25) m/s by using weight of 22.92 kg. The results can be illustrated as in table (5).

Table 5,
Dynamic results of CK45 under 22.92 kg.

H m	V_O m/s	L_o mm	L_f mm	δ mm	P^d_m kN	K.E J	Mode of deformation
0.75	3.834	29.9	25.3	4.6	36.62	168.456	concertina
0.75	3.834	29.9	25.0	4.9	34.378	168.105	concertina
0.875	4.141	29.9	23.7	6.3	31.19	196.51	concertina
1	4.427	30	22.1	7.9	28.43	224.61	concertina
1.25	4.949	30	17.6	12.4	22.64	280.77	concertina
1.375	5.19	29.9	16.2	13.7	22.54	308.8	concertina
1.5	5.422	30	15	15.0	22.46	336.924	concertina
1.625	5.643	29.9	13.5	16.4	22.23	364.68	concertina+ diamond
1.75	5.853	30	12.7	17.72	21.17	392.99	concertina+ diamond
1.875	6.062	29.9	9.93	18.96	21.29	421.155	concertina
2	6.25	30	8.8	21.2	21.2	448.84	diamond
2	6.25	30	8.9	21.1	21. 27	448.84	concertina
2	6.25	29.9	7.6	22.3	20.127	448.84	diamond

3. The Theoretical Aspect (Abramowicz Model)

Bramowicz model is an improvement of Alexander's theoretical analysis [12],[4], for axisymmetric crushing of axially load cylindrical shell (concertina ,ode) and estimates of the effective crushing distance and influence of material rate effects.

From Fig.(6), the circumferential plastic hinges during the crushing of one lobe is :

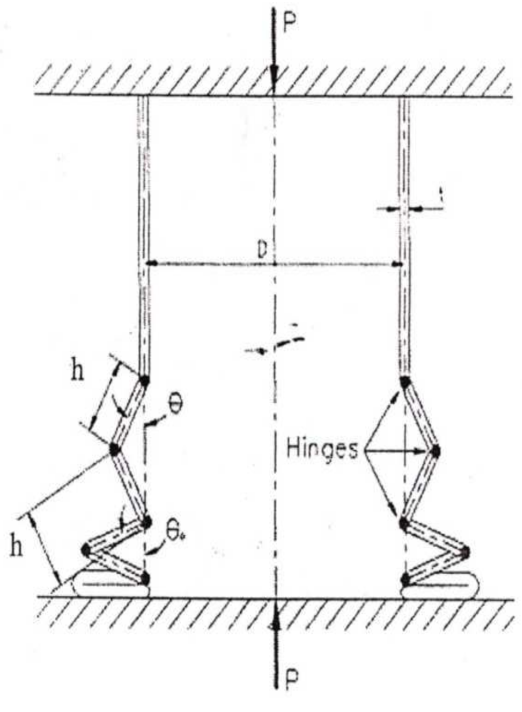

Fig. 6. Idealized model of deformation for axisymmetric concertina mode of an axially compressed circular tube.

$$W_b = 4\pi M_o(\pi R + h) \quad \ldots(2)$$

which is identical to Alexander [12-14].
The stretch plastic hinges is

$$W_c = 2\pi\sigma_y t h^2(1 + \frac{h}{3R}) \quad \ldots(3)$$

The mean crushing load P_m is found from

$$P_m.2h = W_b + W_c \quad \ldots(4)$$

So,

$$\frac{P_m}{M_o} = 20.79\,(\frac{2R}{t})^{0.5} + 11.9 \quad \ldots(5)$$

$$\frac{h}{R} = 1.76(\frac{h}{2R})^{0.5} \quad \ldots(6)$$

Effective crushing distance is [12]:

$$\frac{\delta_e}{2h} = 0.86 - 0.568\,(\frac{t}{2R})^{0.5} \quad \ldots(7)$$

and

$$\frac{P_m^d}{P_m} = 1 + \left(\frac{\dot{\varepsilon}}{2.766}\right)^{0.74} \quad \ldots(8)$$

$$\dot{\varepsilon} = \frac{2\varepsilon_f V_m}{\delta_e} \quad \ldots(9)$$

whereε_f can be found from the following equation

$$\varepsilon_f = 0.88(\frac{h}{2R})^{0.5} \quad \ldots(10)$$

where$\frac{h}{R}$ can be found from Eq.(6)

$$V_m = \frac{V}{2} \quad \ldots(11)$$

In the present work , t=1 mm , D_{in}=16 mm , σ_y= 685 MPa

$$M_o = \frac{\sigma_y.t^2}{\sqrt{2}} \quad \ldots(12)$$

The dynamic load

$$P_m^d = P_m\left(1 + \left(\frac{\dot{\varepsilon}}{2.766}\right)^{0.74}\right) \quad \ldots(13)$$

where $\dot{\varepsilon}$ can be found from Eq.(9) and P_m. From Eq.(5)

And kinetic energy $K = P_m^d . \delta$ …(14)

4. Results and Discussion

The low velocity axial impact of thin-walled circular tubes is taken as quasi-static and the influence of inertia forces is, therefore, ignored. The wrinkles develop progressively and the phenomenon is known as dynamic progressive buckling. In the present study, most of the ck45 steel tubes suffer extensional crushing. Many crushed steel tubes have a mixed type of crushing which consists of type I and type II modes and a general mixed collapse mode is studied. For low velocity impact with large striking masses, the theoretical predictions for dynamic progressive axial crushing of thin-walled circular tubes gives a reasonable agreement with the corresponding experimental results provided the effective crushing distance is recognized and with the average discrepancy about 45%. A theoretical analysis using the basic collapse elements developed by Abramowicz is reported by Abramowicz and Jones [4] for the progressive buckling of thin-walled circular box columns subjected to axial loads, which considers the effective crushing distance, together with the influence of material strain rate sensitivity. Table (6) shows the dynamic mean load theoretical and experimental results with velocity for ck45 steel tube under 22.92 kg dropping mass .

Table 6,
Dynamic mean load (theoretical & experimental) with velocity.

V_O m/sec	K.E J	P^d_m (th) kN	P^d_m(exp.) kN	Discrepancy %
3.834	168.105	36.028	6.6911	81%
4.141	196.51	36.047	8.274	77%
4.427	224.61	36.0593	10.16	72%
4.949	280.77	36.0877	15.95	56%
5.19	308.8	36.101	19.06	47%
5.422	336.924	36.114	22.46	38%
5.643	364.68	36.1267	27.1	25%
5.853	392.99	36.192	30.9	15%
6.062	421.155	36.15	32.41	10%
6.25	448.84	36.163	34.219	5%

And Fig.(7) shows the relation between dynamic mean load (theoretical and experimental) and velocities. It can be indicated that the increasing in the velocity leads to increase in the load in the practical part while it seems to be horizontally linear in the theoretical part, this is due to the assumption of the theoretical model that W_B , the energy dissipated due plastic bending and W_c , the energy dissipated in stretching under substantially uniform tensile yield stress in the metal between the hinges and also assuming the material of the cylinder is rigid-perfectly plastic, then using the notion obvious from Fig.(6), to attain complete collapse of one hinges system (i.e. θ increasing from zero to $\pi/2$).

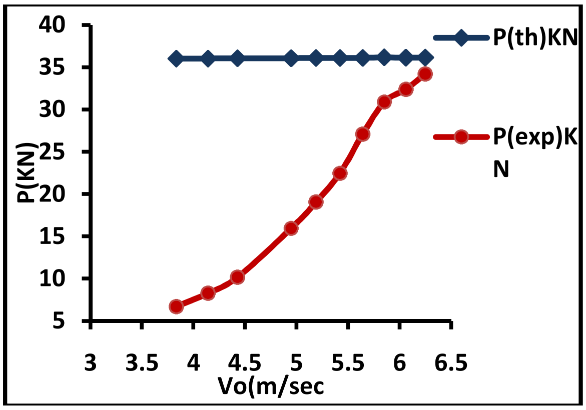

Fig. 7. Shows the relation between dynamic mean load (theoretical and experimental) and velocities.

Fig.(8) represents the results of load (P) which was plotted as a function of kinetic energy (K.E), it is found that P varying with the kinetic energy, and give the same results that were obtained by P and V, this is because to that the kinetic energy extremely related with velocity as :$K.E. = \frac{1}{2}mV^2$, hence the results are the same at which obtained between P and V.

Fig.(9) shows the relation between kinetic energy (theoretical & experimental) with velocity also results are compared with Ayad [15].

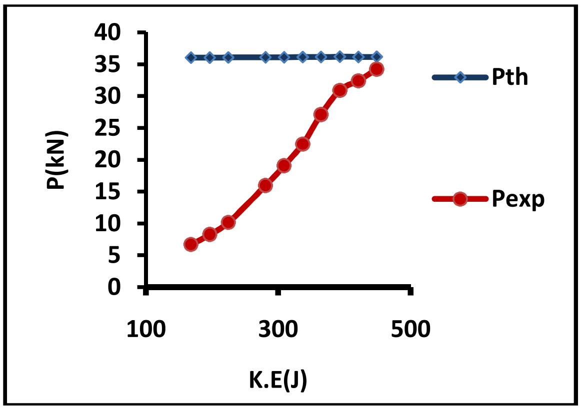

Fig. 8. Relation between dynamic mean load (theoretical & experimental) and kinetic energy.

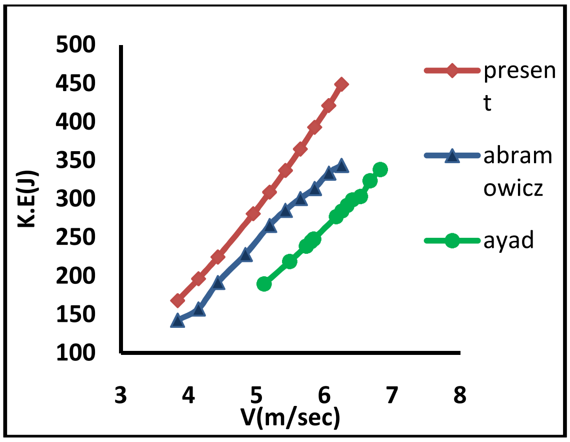

Fig. 9. Relation between kinetic energy (theoretical & experimental) with velocity.

The energy absorbing capability of the impact limiter is controlled by several factors such as energy absorbing capacity, mean crush load, maximum crush load, crush load amplitude, etc. The impact energy absorber should be evaluated for some typical aspects collapse load, energy absorption, and collapse space efficiency. The collapse load is defined as that load required to cause a significant permanent deformation of a particular section of the impacted body. Often, the forces needed to cause significant deformation are of interest since they are relevant to the safety of the contents in the package or the passengers in the vehicle. The amount of deformation is not usually critical at the collapse load. Therefore, the crushing load of cylindrical tube fluctuates with the proceeding of folding. For a practical energy absorber, as shown in Fig.(3), the area under the stress-strain curve for a structure represents the energy absorbed by the structure. The theoretical predictions for dynamic progressive axial crushing of thin-walled circular tubes gives a reasonable agreement with the corresponding experimental results provided the effective crushing distance is recognized for ck45 steel case.

5. Conclusions

1. For elastoplastic collapse deformation, a tube initially goes through elastic deformation , then plastic deformation occurs, after that the tube goes through plastic collapse. As the force decreases, the displacement still increases.
2. Abramowicz model for dynamic impact shows well coincide with discrepancy 45%.
3. It can be indicated that the increasing in the velocity or kinetic energy leads to increase in the load in the practical part while it seems to be horizontally linear in the theoretical part

Notation

D	Diameter of tube
R	Radius of tube
t	thickness of tube
L	original length of tube
P_m	theoretical static crushing load
σ_y	yield stress
σ_u	ultimate tensile stress
P_m^d	theoretical mean dynamic crushing load
V_m	impact velocity of striking mass
E	Elastic modulus
g	acceleration of gravity
E_s	energy absorption
h	collapsed length of tube
δ	deformation

6. References

[1] Mahmoud Reza Amini and SiaNemat-Nasser "Dynamic Buckling and Recovery of Thin Cylindrical Shape Memory Shells". Smart structures and materials, 2005, Active Materials: Behavior of Mechanics, edited by William D. Armstrong. Proceedings of SPIE Vol. 5761.

[2] Z. G. Wei, J. L. Yu, R.C. Batra "Dynamic buckling of thin cylindrical shells under axial impact" International Journal of impact Eng. , 32, (2005), 575-592.

[3] M. Alexander "An Approximate Analysis of the Collapse Thin Cylindrical Shells Under Axial Loading" Quart. J. Mech. Appl. Math. XIII, Pt 1.10,1960.

[4] Abramowicz W. and Jones N. , "Dynamic progressive Buckling of circular and square tubes" , Int. J. Impact Eng., 1986, Vol. 4, No. 4, P243-270.

[5] Gu W, Tang W, Liu T., "Dynamic pulse buckling of cylindrical shell subjected to external impulsive loading". J. Pressure Vessel Technol, 1996, 118: 33-7.

[6] Murase K, Jones N. , " The variation of modes in the dynamic axial plastic buckling of circular tubes". In: Gupta NK editor. Plasticity and Impact mechanics, New Delhi: Wiley Eastern Limited, 1993, P222-37.

[7] Abramowicz W, Jones N., " Transition from initial global bending to progressive buckling of tubes loaded statically and dynamically" Int. J. impact Eng. 1997, 19, p 415-37.

[8] Karagiozova D., Jones N. "On dynamic buckling phenomena in axially loaded elastic – plastic cylindrical shells" Int. J. non-linear Mech., 2002, 37, 1223-38.

[9] W. Johnson , " Impact Strength of Material" , Edward , London, 1972.

[10] Chang Hwan Kim "Development of simplified models for automotive crashworthiness simulation and design using optimization", Ph.D. thesis Graduate College the university of Iowa city, Iowa, 2001

[11] Ku J.K. ,Seo K.S. , Parkland S.W., Kim Y.J. " Axial crushing behavior of the intermittent tack-welded cylindrical tubes". International Journal of Mechanical Science,43 ,PP 521-542, 2001.

[12] Abramowicz W. and Jones N. , " Dynamic axial crushing of circular tubes" , Int. J. Impact Eng., 1984, 2, P263.

[13] Yang, C. C., "Dynamic Axial Crushing of Aluminium Square Tubes", Proceedings of the 18th National Conference on Mechanical Engineering, Taiwan, R.O.C., Vol. 3, pp1033-1040, 2001.

[14] Yang, C. C., "Dynamic Axial Crushing of Square Mild Steel Tubes", The 25th Conference on Theoretical and Applied Mechanics, Taiwan, R.O.C., pp2697-2713, 2001.

[15] Ayad A.K. "low speed impact of thin walled circular tubes", M.Sc. thesis , Al-Anbar university , 2001.

دراسة عملية ونظرية لعملية الاصطدام الحركي اللدن لمعدن CK45

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الخلاصة

تم في هذا البحث دراسة تصادم بسرعة منخفضة لانابيب رقيقة الجدران الدائرية من معدن ck45 . وقد تم دراسة تطور التجاعيد تدريجيا وتعرف هذه الظاهرة بديناميكية تقدم الانبعاج. في هذا البحث، ثم اجراء الدراسات العملية والنظرية على حالة الانبعاج اللدن المتقدم نتيجة تعرض الانبوب الدائري الى حمل تصادم محوري من خلال تصميم وبناء جهاز لدراسة سلوك ck45 تحت تأثير سرعة صدمة منخفضة m/s (3.8 الى 6.25).

يتألف العمل من الجزء العملي والجزء النظري (نموذج براموكس) لامتصاص الطاقة والاحمال الحركية تحت سرع مختلفة. عند ازدياد سرعة التصادم، فان قيمة اجهاد السحق الديناميكية لـck45 سوف تزداد. أيضا لانهيار ذي التشوه المرون-اللدن حيث ان الأنبوب يمر في البداية من خلال تشوه مرن، ثم يحدث تشوه اللدن، وبعد ذلك فان الانبوب يحدث به الانهيار اللدن . حيث ان القوة تقل، فان التشويه يستمر بالزيادة. نموذج براموكس لتأثير الديناميكي اظهر تتطابقا في النتائج بشكل جيد مع تفاوت حوالي ٤٥٪. وايضا يمكن الإشارة إلى أن زيادة في السرعة أو الطاقة الحركية يؤدي إلى زيادة في الحمل في الجزء العملي في حين تبدو العلاقة خطية أفقية في الجزء النظري.