Determination Formability of Tubular (AL-alloy) by Hydraulic Bulge Test

Dr. Azal Rifaat Ismail
Production and Metallurgy Engineering Department, University of Technology/Baghdad
Waqass saad
Production and Metallurgy Engineering Department, University of Technology/Baghdad
Email:Waqass_s@yahoo.com

Received on: 10/3/2014 & Accepted on:8/10/2015

ABSTRACT

This study aims to establish the forming limit diagrams of tubular material by bulge test. The bulge test applies internal (hydraulic) pressure with and without applied axial feeding on tubular specimen causing tube expansion, undergoing plastic deformation until bursting occurs.

In order to investigate bulge test, a hydraulic bulge tool has been designed and manufactured with insert dies having profile die radius (10) mm. the fixed bulge and the bulge with axial feeding can be fulfilled by this tool. Axial feeds applied to tube ends were (1, 3, 5, 7) mm. The process has been carried out using aluminum alloy (6063) tubes with dimension of ($d_\circ = 50$, $t_\circ$ =1.7, $L_\circ$ =150) mm before and after annealing.

Before doing the bulge test, tubes were annealed at temperatures of (425) °C with holding time of two hours and then cooled in the furnace. Square grids have been printed on all tubes wall with dimension (5x5) mm. The grid was printed by screening method to calculation major and minor strain. A commercially available finite element program code (ANSYS11.0), was used to perform the numerical simulation of the bulge test.

Maximum bulge height without axial feeding that can be obtained from tubes annealed at 425°C was (4.62) mm with bursting pressure of (7.5) Mpa and final tube thickness of (1.42)mm. When applying axial feeding the max bulge height is(4.95)mm with bursting pressure of(9.5)Mpa and final tube thickness of (1.55)mm these results obtained from axial feeding(5)mm, wrinkling occurs when applying axial feeding(7)mm.

Strain calculation was performed using software program (Matlab). The strain value was obtained by measured grid dimension before the bulge test and grid dimension after bulge test for tubes at all annealed temperatures and applied axial feeding.

It is noted that good agreement between experimental and numerical results, the maximum error is 5.2%.

Keywords: Forming limit diagram,Bulge,Anneali

حساب قابلية التشكيل لانابيب الالمنيوم السبائكي بواسطة اختبار الانتفاخ

الخلاصة

يهدف البحث الى انشاء مخططات حدود التشكيل القصوى لأنابيب الالمنيوم السباكي بواسطة اختبار الانتفاخ.اختبار الانتفاخ هو تسليط ضغط داخلي(هيدروليكي) بتغذية او بدون تغذية محوريه على عينة انبوبية الضغط يسبب تمدد الانبوب مرورا بتشوه لدن لحين حدوث الانفجار.من أجل تحقيق اختبار الانتفاخ تم تصميم منظومة اختبار الانتفاخ مع قوالب داخلية بنصف قطرتقوس (١٠)مم.اختبار الانتفاخ الثابت والانتفاخ مع تغذيه محوريه يتم اجراءها بواسطة هذه المنظومة.التغذية المحورية المسلطة على نهايات الأنابيب

https://doi.org/10.30684/etj.34.2A.5
2412-0758/University of Technology-Iraq, Baghdad, Iraq

هي(١,٣,٥,٧)مم.العملية يتم اجرائها على أنابيب الألمنيوم السبائكي(٦٠٦٣) بأبعاد $(d_{\circ} = 50$, $t_{\circ}$ =1.7 , $L_{\circ}$ =150)مم.
قبل اجراء اختبار الانتفاخ الأنابيب يتم تلدينها بدرجات حرارة°C (٤٢٥) ولمدة ساعتين ثم تم تبريدها داخل الفرن. تم طباعة شبكات مربعة على جدار الأنابيب وبأبعاد(5x٥)مم لجميع الأنابيب لاجل حساب قيم الانفعال. تمت المحاكاة باستخدام طريقة العناصر المحددة التي تم تنفيذها باستخدام برنامج(ANSYS 11.0) الخاص بتقنية العناصر المحددة لأنجاز اختبار الأنتفاخ .
تم الحصول على اقصى انتفاخ بدون تسليط تغذية محورية من الأنابيب التي تم تلدينها بدرجة حرارة ٤٢٥°C هو(٤.٦٢)مم وبضغط انفجارMpa (٧.٥) والسمك النهائي للأنبوب(١.٤٢)مم. عند تسليط تغذية محورية اقصى انتفاخ هو(٤.٩٥)وبضغط انفجارMpa(٩.٥) والسمك النهائي للأنبوب (١.٥٥)مم هذه النتائج يتم الحصول عليها بتغذية محورية(٥)مم. الانبعاج يحدث عند تسليط تغذية محورية(7)مم.
حساب الانفعال تم انجازه بواسطة برنامج(Matlab)،قيم الانفعال يتم الحصول عليها بالمقارنة بين ابعاد الشبكة قبل اختبار الانتفاخ وابعاد الشبكة بعد اختبار الانتفاخ .
تم ملاحظة تقارب النتائج العملية ونتائج المحاكاة الرقمية وان اعلى نسبة خطأ هي (٥.٢)%.

INTRODUCTION

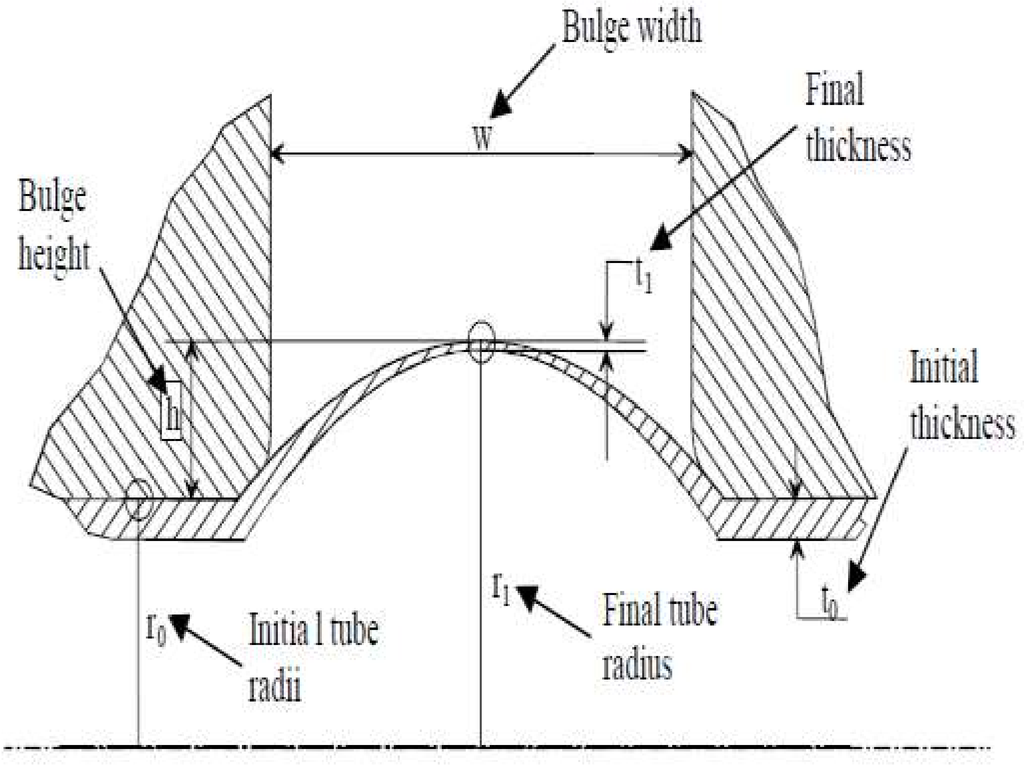
In order to obtain reliable data on material properties of the tube, a test procedure should be used, that is as close as possible to the hydroforming process. Although the results of the tensile test can provide information about the stress-strain relationship, they can hardly be used to evaluate formability of tubes for hydroforming, since the tensile test induces a uniaxial state of stress, while the THF process is mainly biaxial. In other words, a test generating a biaxial tensile stress state in the sample (such as a bulging test) would be closer to the real process conditions and this would insure a much more effective evaluation of formability. The principle of the bulge test is very simple: a metal tubular specimen is loaded with internal pressure (usually hydraulic) and expands, undergoing plastic deformation until bursting occurs by measuring the internal pressure and the tube deformation at the apex of the tube [1].

The geometry of the tube bulge test as shown in Figure (1).bulge test is very simple and therefore suitable to be used on any hydroforming press. And used as system tool, In fact, it does not require any other sensors than a pressure-recording device: several tubes of the same material are tested at different pressure levels, and the deformations (strains and bulge height) are measured after each tube is extracted from the tooling [2].

Zhu bin He, Yanli Lin [3], carried out a bulge test at different temperatures from RT up to 480 °C. To evaluate the formability of AZ31B extruded tube. Bursting pressure and maximum expansion ratio (MER) of the tube were obtained. The bursting pressure decreased almost linearly as testing temperature increased and the hardness value of the tube decreased significantly after the bulging test at elevated temperature, MER value remains almost unchanged from RT to100°C. and about30. 3% expansion ratio was reached at 480 °C. Fuchizawa et al [4].used hydraulic bulging of tubes determining the stress-strain characteristics of tubular materials by annealed aluminum, copper, brass and titanium tubes were tested under only internal pressure. With the instrumentation and control systems available, tube thickness, radius of curvature in both longitudinal and hoop directions, and internal pressure measured and recorded during formation of the bulge. Using analytical methods were derived stress-strain relations. These findings were also compared with those obtained from tensile tests. Stress-strain relations for aluminum, copper and brass were found to be similar by two tests, whereas that for titanium were different. Since they did not use axial compressive load during bulging, stress-strain relation obtained was limited to low strain values up to (0.7).

A. S. Selvakumar, et.al [5], studied the effect of the deformation characteristics of tubular materials before and after heat treatment in hydroforming process. The test was carried out by placing the tube into the die and filling the tube completely with fluid. The experimental work was performed on aluminum, brass and mild steel tubular materials of thickness 1.5 mm, and diameter 38 mm. The movement of punch provided both axial feeding of the tube and increasing pressure inside the tube. The experimental work was performed in two phases. In phase I, without heat treatment process, in phase II, after annealing treatment to tubular specimens, the annealed specimens showed better permeability than those without heat treatment. By proper annealing treatment, leakage arresting and suitable punch movement, the desired shape of the component without failure was obtained.

Mehdi Safari,Seyed Jamal Hosseinipour[6], calculated forming limit diagram for aluminum alloy 3105 is performed experimentally and forming limit based on stress (FLSD) numerical prediction by ductile fracture criteria. Using simulation is considered. The strain paths from finite element simulations are found fairly acceptable to represent both sides of the FLD. The necessary strain paths are obtained by using different sample widths .Finite element showed FLD and FLSD predicted by ductile fracture criteria are in good in agreement with results obtained from experimental work.



Figure(1) Geometry of the deformed tube.

Experimental Procedure

The bulge test has been carried out by designed and manufactured the bulge tool set shown in Figure(2). The tooling is applicable to tubes of various material, wall thickness and diameters. There is no need to change any hard tooling for material and wall thickness changes, various THF processes can be performed through the tooling.

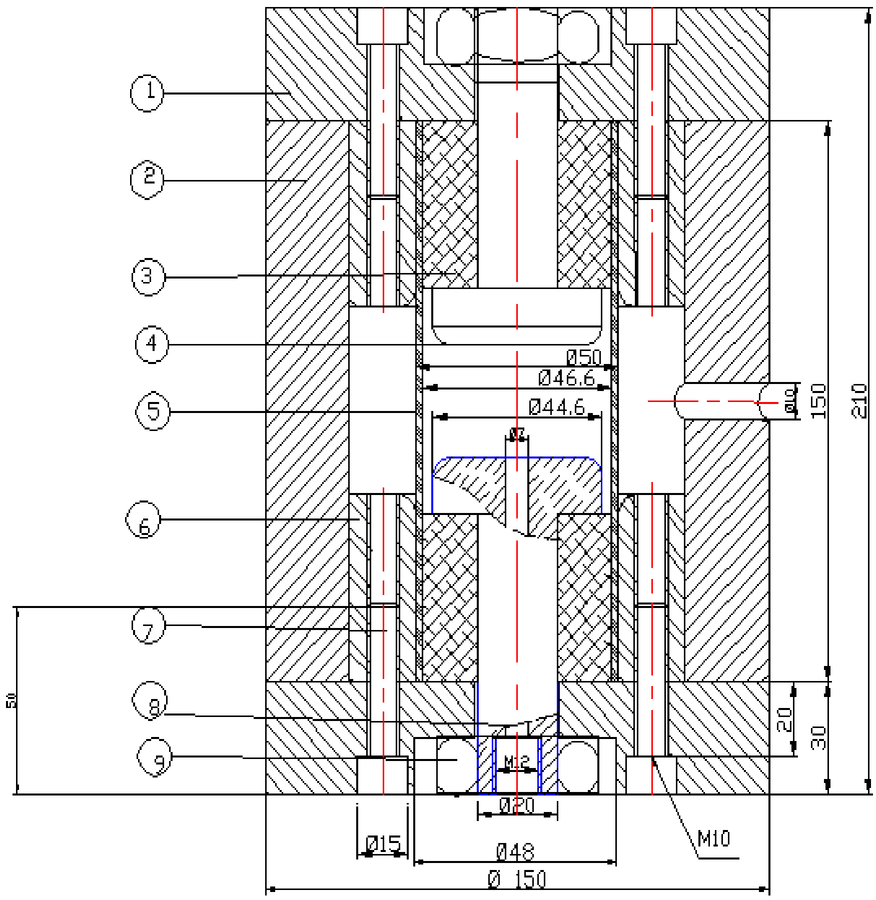
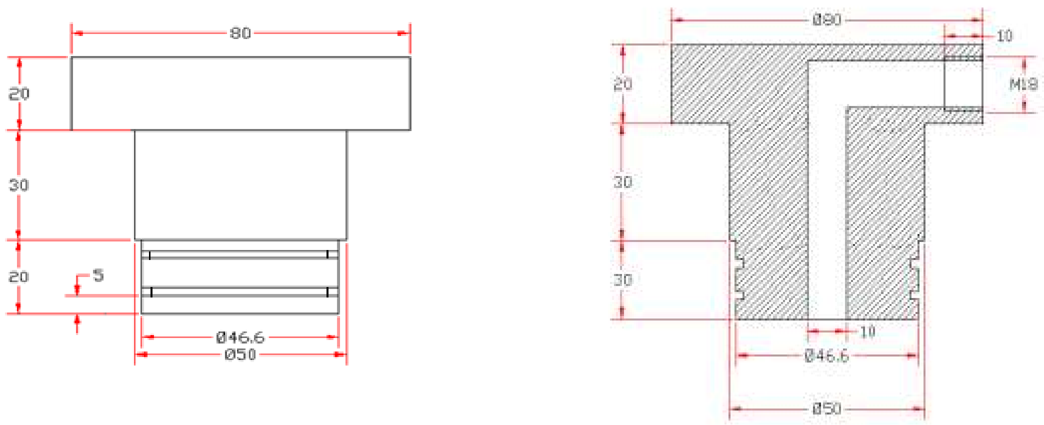


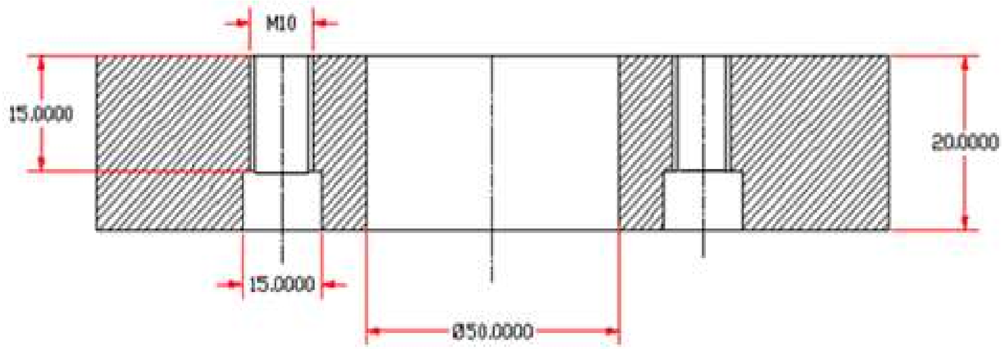
Figure (2) Bulge Tool Set.

Part NO.	Part name	Quantity	Material
1	Plate	2	Steel
2	Container	1	Steel
3	Rubber	2	Rubber
4	Solid shaft	1	steel
5	Tube	1	Aluminum
6	Insert die	2	steel
7	High tension bolt(M10)	8	steel
8	Hollow shaft	1	steel
9	Nut(M20)	2	Steel

In order to provide axial feeding at the end of the tube in the bulge test two punches are designed one is solid and the other is hollow as shown in Figure (3), the hollow punch was used to allow hydraulic fluid to flow to the tube, upper and lower plate replaced when applied axial feeding as shown in Figure (4),. The bulge testing with applied axial feeding is shown in Figure (5).



Figure(3)Solid and Hollow punches.



Figure(4) Upper and Lower Plate

Figure (5) applied axial feeding.

The end cover and container which also serves as a guiding sleeve are held together by bolts, whereas on the side of the container one holes are properly machined for a dial gauge in order to permit the measurement of the bulge height. The insert die and end cover are held together by bolts and the tube insert in the die .the pressure source is applied by pass the hydraulic fluid through the hollow shaft to the tube .The strains in bulge test can be determined by following equations.

$$\epsilon_1 = \ln(\rho_1/\rho_\circ) \qquad \ldots\ \ldots\ldots(1)$$

$$\epsilon_3 = \ln(t_i/t_\circ) \qquad \ldots\ldots\ldots(2)$$

$$\epsilon_1+\epsilon_2+\epsilon_3 = 0 \qquad \ldots\ldots\ldots(3)$$

Where

$\rho_\circ$	Initial tube radius	mm
ρ_1	Instantaneous circumferential tube radius	mm
t_i	Instantaneous tube wall thickness	mm
$t_\circ$	Original tube wall thickness	mm
ϵ_1	Circumference strain	
ϵ_3	Thickness strain	
ϵ_2	Longitudinal strain	

Numerical simulation

Numerical simulation provides a cost-effective way to explore the performance of products or processes in a virtual environment. This type of product development is termed virtual prototyping. Virtual prototyping techniques enable a reduction in the level of risk, and in the cost of ineffective designs. The multifaceted nature also provides a means to ensure that users are able to see the effect of a design on the whole behavior of the product.

Contact rigid-flexible used in this model to represent the contact procedure

Between die(rigid)and deform tube(flexible).

The 2-D 4-node plastic solid structural element VISCO106 was used for modeled tube which defined by four nodes having up to three degrees of freedom at each node.

The contact elementCONTA171was used to represent the deformable material and used the target element TARG169 to represent the die.

Isotropic Hardening Plasticity model was used, the plastic response was modeled using the Von Mises Yield Criterion with modulus of elasticity ٦٩Gpa and passions ratio 0.3.Due to the symmetry in the geometry of the tube in free bulge hydroforming only (1/2)portion was modeled and define as axisymmetry to represent full tube in solution. In this model used aluminum alloy (6063)tube after heat treatment and with applied axial feeding.

Results and Discussions

The experimental test was carried out at different pressure levels to obtain the relationship between bulge height and internal pressure. From this relationship can be determine the deformation and thinning percentage by measuring bulge height and wall thickness after tube bursting. Figure (٦) shows the bulge test at annealing temperature (425) °C.

Figures (6), represented the bulge test carried out with tube annealed at temperature (425)°C. From this Figure the max bulge was obtained from these tubes are (4.65) mm and, bursting occur at pressures (7.5) Mpa and yield pressure are(3)Mpa. The max bulge radius occurs in the center of the tube also the bulge has symmetry distribution above and below the tube center, Figure (7) show the bulge distribution along longitudinal axes of the tube. Figure (8) show the thickness and radial strain distribution above and below tube center. at 425°C the maximum thinning was obtained (17.6) % from tube annealing at425°C when thickness reduced from (1.7 to 1.4).

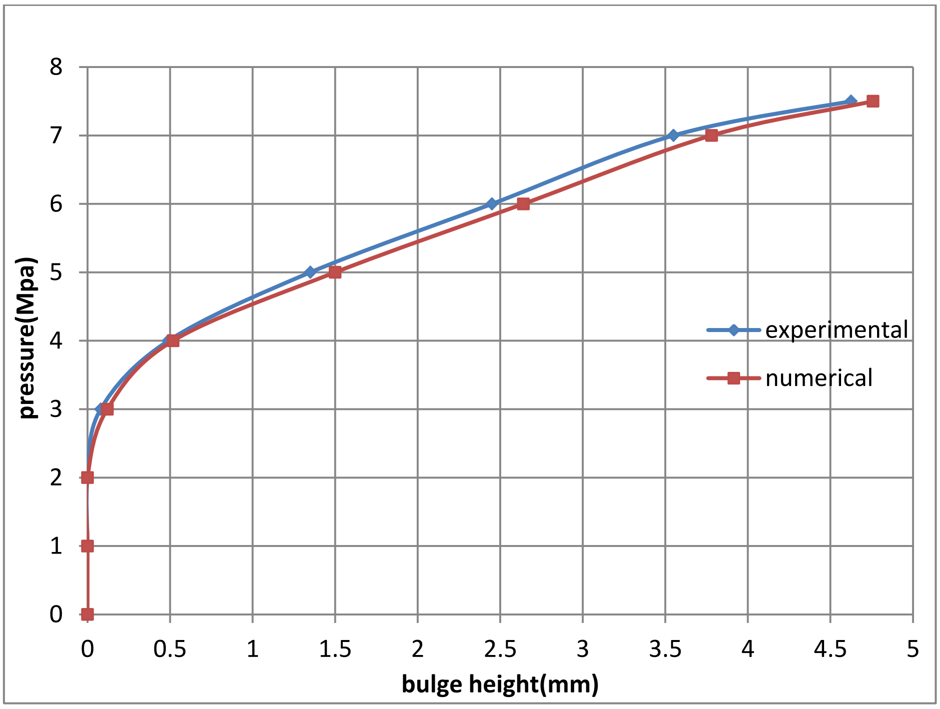


Figure (٦) Relationship between pressure and bulge height for tube annealing at 425°C

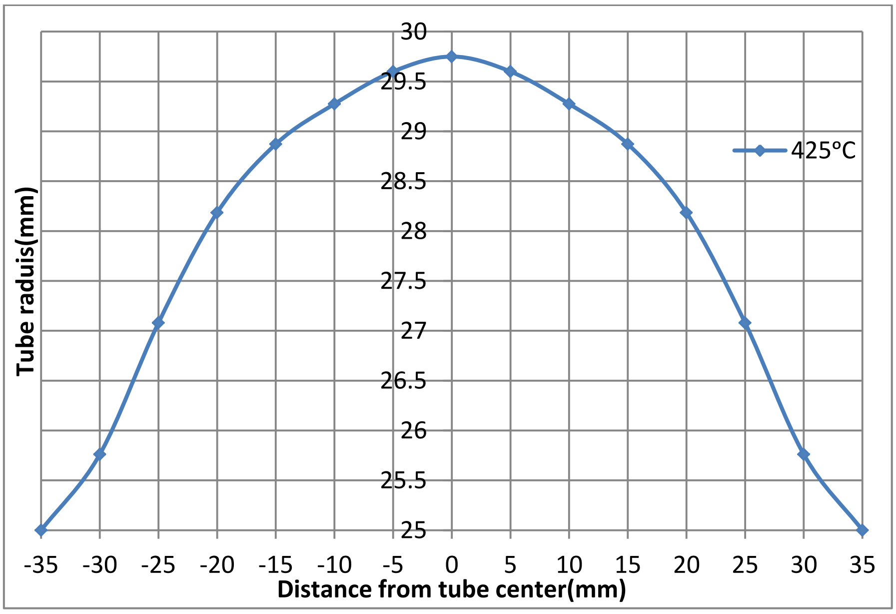
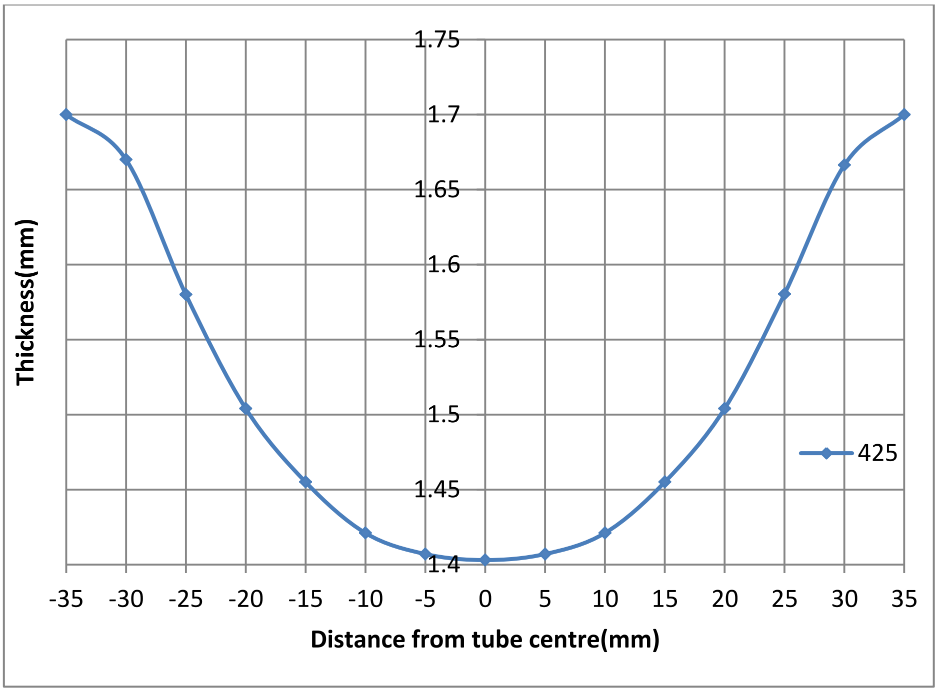
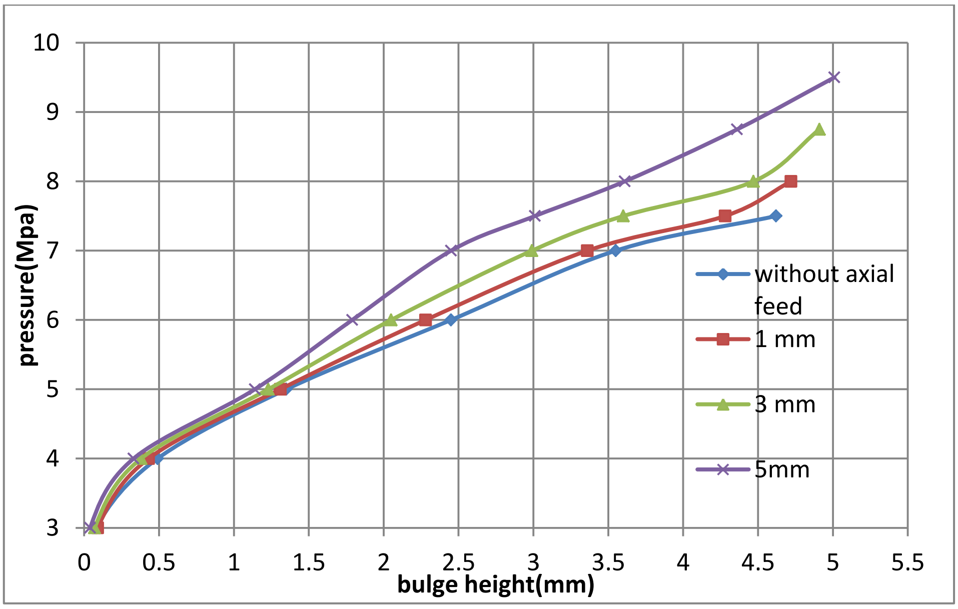


Figure (٧) Bulge distribution.

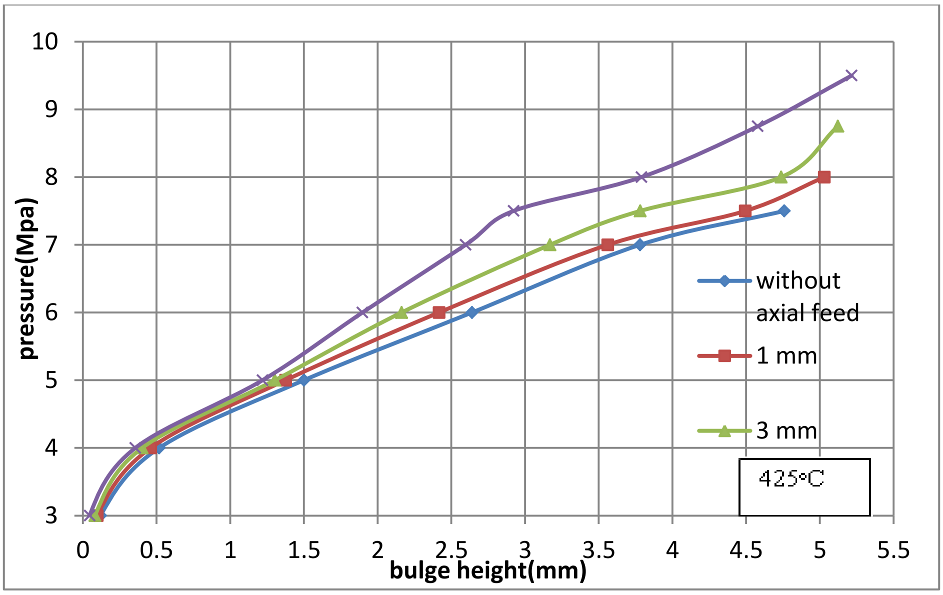


Figure(٨) Numerical Thickness distribution.

The axial feeding was applied to the end of the tube to obtain negative strain (tension-compression) for left side of the forming limit diagram. The experimental and numerical tests were carried out with axial feeding (1,3, 5 and 7) mm. The effect of the axial feeding on the bulge are shown in Figure (9), and the wrinkling occurs when using feed 7mm .Figure (10) shows the wrinkling which occurs in the experimental and numerical tests. The pressure increases with axial feeding and the percentages of the pressure increase are (21)%,and percentages of increasing for bulging at axial feeding 1mm and 5mm is (5.7) %respectively.



(a)



(b)

Figure (٩) (a) Experimental results at annealing temperature 425°C.

(b) Numerical results at annealing temperature 425°C.

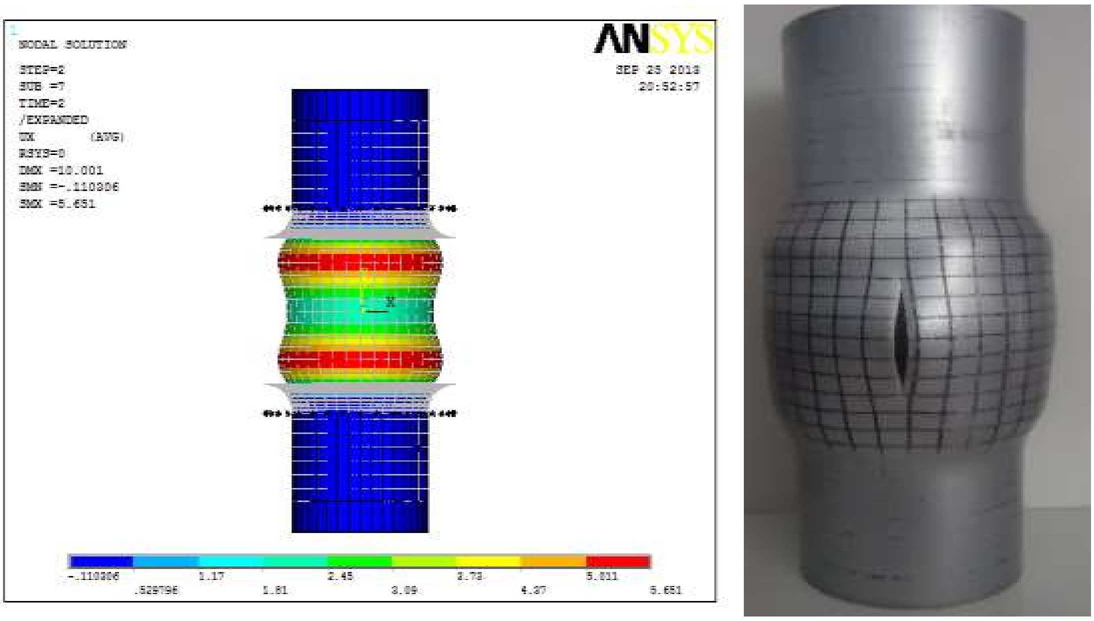


Figure (١٠) Wrinkling at 7mm axial feeding.

Figure (11) represent the forming limit diagram of aluminum tube .The right side was obtained from bulge test without any axial feeding (tension-tension) and internal pressure is applied only. The left side is determined by applied axial feeding to the end of the tube. The point in plane strain is equal to (n) strain hardening exponent. From these forming limit diagram. The strain hardening exponent (n) is (0.145) .

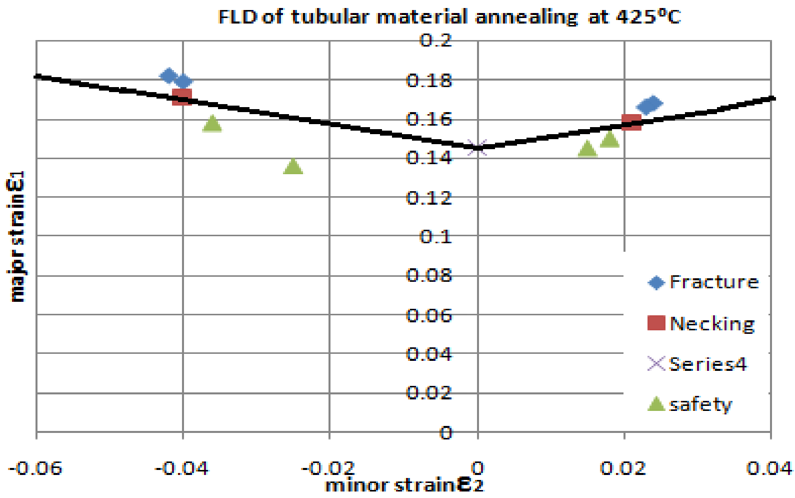
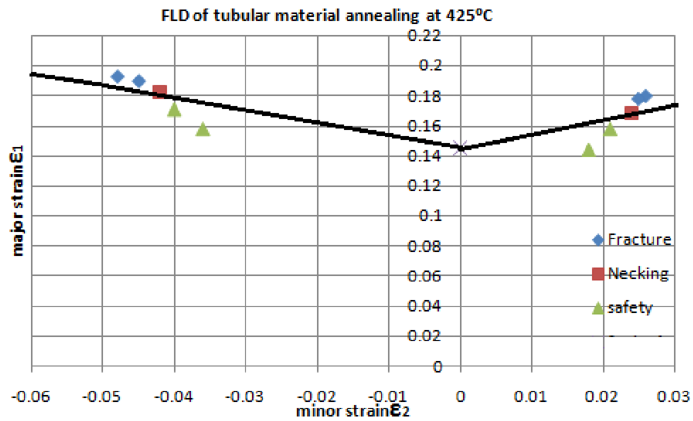


Figure (11) (a)



(b)

Figure(١١)(a) Experimental FLD of tubular material annealed at 425°C.
(b) Numerical FLD of tubular material annealed at 425°C.

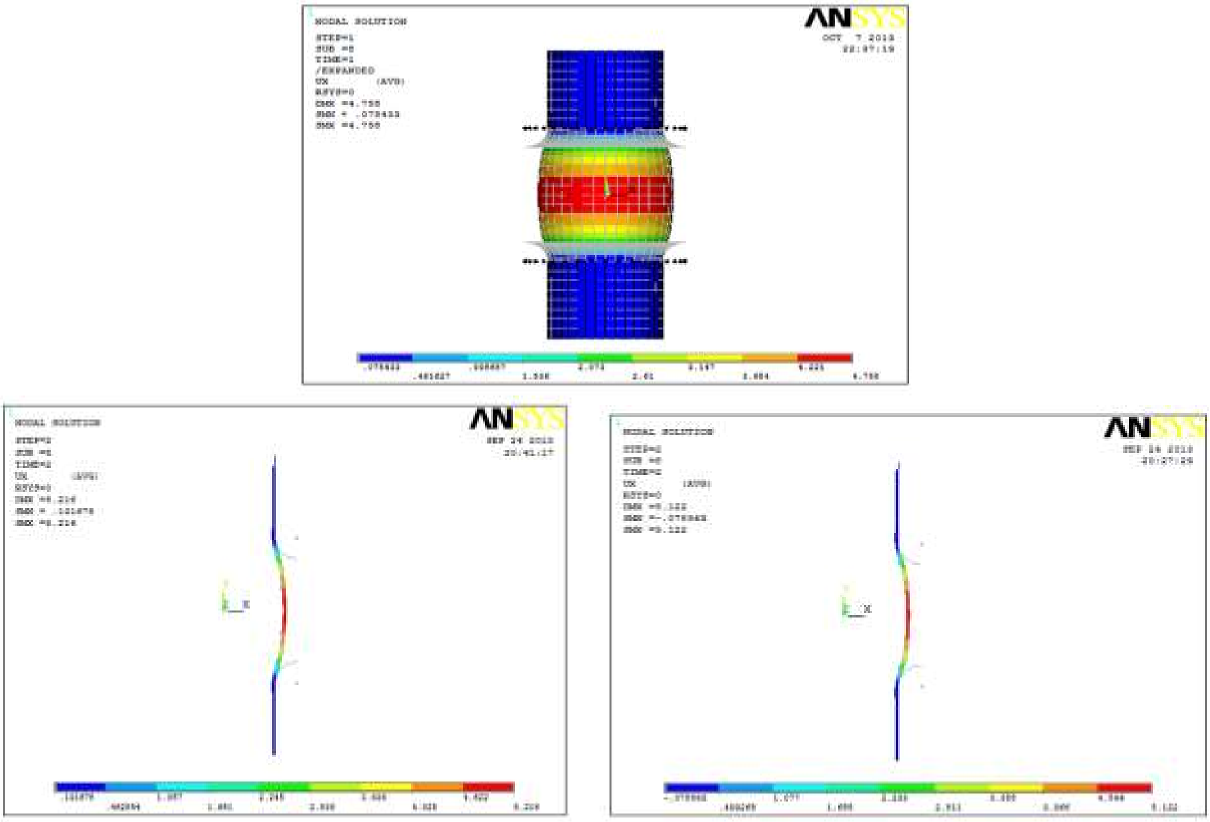


Figure (١٢) Numerical Result

Figure (١٣)Bulge test at different axial feeding.

CONCLUSION

1- The bursting pressure increases with axial feeding and the maximum percentages of the pressure increase are (21) %

2-The maximum bulge for tube increases with applied axial feeding to tube end and the maximum percentages of the increase are (5.7) %.

3- Thinning for tube decreases with applied axial feeding to tube end.

REFRENCES

[1]Rees, D.W.A., 1995.” Instability limits to the forming of sheet metals” J. Mater. Process. Tech. (1995), 55, 146-153.

[2]Altan T., Koc M., Aue-u-lan Y., Tibari K., 1999.” Formability and design issues in tube hydroforming, Hydroforming of Tubes Extrusions and Sheet Metals” vol. 1. Ed. K. Siegert.

[3] Zhubin He, Yanli Lin, Jia Wu, and Shijian Yuan” Study on the Formability and Deformation Behavior of AZ31B Tube at Elevated Temperature by Tube Bulging Test” Journal of Materials Engineering and Performance, 10.1007/s11665-010-9744-8.

[4]Fuchizawa, S., Narazaki, M” Bulge Test for Determining Stress-Strain Characteristics of Thin Tubes” Advanced Technology of Plasticity pp. 488-493, 1993.

[5]A. S. Selvakumar, K. Kalaichelvan, S. Venkataswam” Effect of Heat Treatment Process on Hydroforming of Tubular Materials” European Journal of Scientific Research, Vol.68 No.3 (2012), pp. 377-388.

[٦] Mehdi Safari1*, Seyed Jamal Hosseinipour, Hamed Deilami Azodi, “Experimental and Numerical Analysis of FormingLimit Diagram (FLD) and Forming Limit StressDiagram (FLSD)” Materials Sciences and Applications, 2011, 2,pp 497-503.