Mansoura Engineering Journal

Volume 17 | Issue 2 Article 6

6-1-2021

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Recommended Citation

Ibrahim, Magdy (2021) "The Use of Bore-Expansion Test for Determining the Influence of Anisotropic Yielding on the Formability of Metal Sheets.," *Mansoura Engineering Journal*: Vol. 17 : Iss. 2 , Article 6.
Available at: https://doi.org/10.21608/bfemu.2021.167361

THE USE OF BORE-EXPANSION TEST FOR DETERMINING THE INFLUENCE OF ANISOTROPIC YIELDING ON THE FORMABILITY OF METAL SHEETS

استخدام اختبار تمدد الثقب لتعيين تاثير الخضوع الانزوتروبى على قابلية التشكيل للالواح المعدنية

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خلاصه : فى هذا البحث تم نظريا تعيين الخضوع الانزوتروبى للمعادن المشكلة تحت تاثير عدد كبير من العوامل المؤثرة مثل صلادة الانفعال ومعدل حساسية الانفعال باستخدام الحاسب الالى (التحليل العددى للمحددات الصغيرة FEM) بناء لمعايير بسانى للخضوع ومقارنتها عمليا باستخدام اسطمبه سحب خاصة واقراص مثقوبة مركزيا من : صلب سحب عميق - صلب منخفض الكربون نحاس اصفر ٧٠ /٣٠ . وتم استنتاج ان معايير بسانى للخضوع مفيد فى تحديد درجة قابلية التشكيل لهذه المعادن فقط عند قيم محدده لـ r^* (وهى احدى خواص المعادن عند الخضوع الانزوتروبى) .

SUMMARY- In sheet metal forming operations, formability is usually governed by a great number of parameters such as strain hardening, strain rate sensitivity, and the shape of anisotropic-yield loci.

In the present work, the deformation and formability in bore-expanding were examined theoretically and experimentally from aspect of the shape of anisotropic yield loci employing Bassani yield criterion.

According to this criterion, a numerical analysis was performed for axi-symmetrical bore-expanding using three investigated materials, AL-Killed steel, EG- low carbon steel, and Brass 70/30. The bore-expanding limit was also studied using various necking theories and results were compared with the experimentally determined values. It was concluded that Bassani criterion was useful to predict the deformation and formability in bore-expanding test only at a certain value of r^*.

INTRODUCTION

Forming processes are among the most important to metal - working operations. Deep drawing and stretch forming, which are used to shape flat sheets into nondevelopments. This is due to the ease with which complex parts can be manufactured at high rates of production. Sheet metal forming, however, is an industrial process strongly dependent on numerous interactive variables such as material behaviour, forming equipment, lubricantion ... etc. In the last few years, the correct choice of these parameters has appeared as one of the main aims of the automobile industry in order to reduce fuel consumption through weight reduction of autobody panel and to achieve high mechanical and aesthetical characteristics. Laboratory simulative tests have allowed researchers to study the influence of tool design and lubrication on the deformation factors. This has led to the development of the modern concepts of formability (localized necking, fracture), and shape fixability.

Uptil now various yield theories have been proposed to describe such properties and their validity has been discussed [1-4]. Attention was restricted to limit independent smooth yield criteria. Hill's quadratic criterion [5 , 6], known as Hill,s old criteria, has been widely used. Such criteria was the first to describe localized necking in thin sheets for deep-drawing. It failed, however, to predict the biaxial yield strengith of materials having R - values less than unity. This was first pointed out by Woodthorpe and Pearce [7], named "anomalous behaviour". In order to encompass the anomaly, Parmar and Mellor [8] proposed a new function and Bassani [9] presented a more general description. Hosford [10] indepenedently proposed a modification of Hill's old form, and Gotoh [11] advanced the biquadratic function. Previous investigation by Kurosaki et al. [12] made a comparison between the applicability of biquadratic, Bassani , Hill's old and new forms criterion. Based on this comparison, it was concluded that, though Bassani's criterion has a few intrinsic problems, it is most useful in anisotropic problems. In addition, it has the flexibility to express various types of yielding.

Recent studies on sheet metal forming have shown that the anisotropic yield charactaristics is an important rule in the sheet deformation process. It is therefore of major importance to extend the plastic instability analysis to anisotropic materials.

The aim of this work is to clearify the infeleunce of anisotropic yielding on the deformation and formability in axi-symmetrical bore-expanding of metal sheets by using the Bassani criterion [9]. state of plane stress and planar isotropy were not taken into consdiration in this paper.

NOTATION

σ_θ = Circumferential Stress
σ_r = Radial Stress.
σ_e = Fffective Stress.
m^*, n^*, r^* = Material parameters, characterizing anisotropic yielding
σ = $\sigma_\theta + \sigma_r$
τ = Maximum shear stress
B = $(n^* / m^*) (1 + 2r^*)$
$d\varepsilon_\theta$ = Increment of the circumferential strain.
$d\varepsilon_r$ = Increment of the radial strain
$d\varepsilon_z$ = Increment of the thickness strain
d_o = Original blank diameter ($d_o = 2r_o$)
r_o = Original radius of blank
r_c = Current radius
t_o = Original thickness of blank
t = Current thickness.
ε_{zo} = Thickness strain at the hole edge
n = Strain hardening exponent
R = Anisotropic parameter
K_o = Flow stress of the material.

ANALYSIS OF BORE - EXPANDING

The deformation behaviour in bore-expanding of sheets with normal anisotropy was analysed by Parmar and Mellor using Hill's new function and its associated based on Bassani criterion was performed. The axi - symmetrical bore-expanding with a flat-headed punch is illustrated in Fig.1. Fundamental equations used are as follows.

$$\left|\sigma_\theta + \sigma_r\right|^n + B\sigma_e^{n-m} \left|\tau\right|^m = (1+B)\,\sigma_e^n \qquad \ldots (1)$$

If m* = n* Eq.(1) is reduced to Hill's new form. This is also reduced to Hill's old form when m* = n* = 2. If m* = n* = 1 and r* = 0, Eq.(1) reduces to Tresca criterion on the quadrants I and II of the $\sigma_\theta - \sigma_r$ plane. Typical yield loci in quadrant I are illustrated in Fig.2.

Flow rule associated with Eq.(1) at $\sigma \geq 0$ and $\tau \geq 0$ is given by

$$\frac{d\varepsilon_\theta}{(\sigma_\theta+\sigma_r)^{n^*-1}+(1+2r^*)(\sigma_\theta-\sigma_r)^{m^*-1}\sigma_e^{n^*-m^*}} = \frac{d\varepsilon_r}{(\sigma_\theta+\sigma_r)^{n^*-1}-(1+2r^*)(\sigma_\theta-\sigma_r)^{m^*-1}\sigma_e^{n^*-m^*}}$$

$$= \frac{-d\varepsilon_z}{2(\sigma_\theta+\sigma_r)^{n^*-1}} = \frac{d\varepsilon_e}{[1+B]\sigma_e^{n^*-1}+(1+2r^*-B)(\sigma_\theta-\sigma_r)^{m^*}\sigma_e^{n^*-m^*-1}} \qquad \ldots (2)$$

Equilibrium equation in the radial direction is as follows

$$d(t\sigma_r)\,dr = t(\sigma_\theta - \sigma_r)\,r_c \qquad \ldots (3)$$

Incompressibility condition is represented by

$$d r_c / dr_o = t_o r_o / (t\, r_c) \qquad \ldots (4)$$

The main procedure for the numerical calculations employed is based on the finite difference method, presented by the **Parmar** et. el. and **Yamada** [13,14]. A program for numerical iteration was developed to determine the stress components from the strain components and their increments.

Theoretical Analysis

In the beginning it was confirmed that the numerical solution obtained in this study about nearly according to **Parmar** and **Mellor** [13]. Then, calculation was carried out for the blanks having initally D_o of 100 mm outside diameter, a hole diameter d_o of 10mm, a thickness to of 1.0mm and the theoretical values of anisotropic properties is given in Fig.2. The radial distribution of ε_θ and ε_z computed at ε_{z0}= -0.20 is shown in Fig.3. The difference of ε_θ among the yield types except Tresca is less than that of ε_z. In curves, 1,2, and 4, having relatively large equibiaxial stresses, ε_z simply increases with the increase of the original radius r_o. The ε_z distribution in **Bassani** curve 3 was considered in this study as, it causes the maximum thinning at a specific radial position, but not at the hole edge. It was assumed that the neck and fracture would initiate at the hole edge. This phenomenon has often been encountered in actual bore-expanding, but is difficult to predict theoretically by any other yield criteria with planar isotropy. This work shows that such a phenomenon is possible only by Bassani type yielding with $m^* < 2$ and $n^* > 2$ (curve 3). An apparently similar distribution is also possible by Hill's old form with planar anisotropy [15], but it comes out at a specific direction not related to necking initiation.

Experimental Work

Three materials were tested in this study; namely, **Electro-Galvannealed** low carbon steel sheet, **Al-Killed** steel, and **Brass 70/30**. All the materials under study were cold-rolled to a sheet thickness of approximately 1.0mm.

Uniaxial testing was carried out with a **100 KN INSTRON** universal testing machine. The strain rate applied in the tests approached $1.2*10^{-3}$/s. Three standard tensile specimens of 12.0mm width and 70mm gauge length were prepared from each material at 0°,45° and 90° to the rolling direction. The R-values were measured at (14%-17%) elongation. Each of the stress-strain relation was refered to **Swift** formula [16]. The chemical composition and mechanical properties of the as-recevied materials are listed in **Tables** 1,2 respectively.

Conventional bore-expansion test using a flat punch in a fashion similar to the **KWI** test. The hole was expanded by the punch until fracture occured at the deformed edge. Blanks with an outer diameter 100mm were prepared from each investigated material and then bored with a central hole ranging from 4mm to 15mm in diameter.

The geometry of the bore-expanding test rig is shown in Fig.4.

The punch head was lubricated with mineral oil and graphit grease, while the surfaces of the die and blank holder were lubricated with graphit grease. The blank holding forces were 10KN for **Al-Killed** steel, 9.7 KN for EG low carbon steel,and 6.5 KN for **Brass** 70/30. The punch speed was 20mm/s. Strain was measured using a contact circles grid of 2.0mm in diameter. Each blank was printed photo-chemically on its surface [17]. After blanks straining, the circles were deformed to ellipses, both close to and within necking or fractured areas and measured using the travelling optical microscope to determin the strainsε_θ and ε_r , The grid circles were also used as reference points for measuring the thickness strainε_z.

Results and Discussion

Since **Bassani** yield function involves three material parameters, three kinds of fundamental tests are required in principle to determine the function. The procedure is tedious except for the R- values, and thus their actual values which were measured before. The indices m' and n' were selected so that the theoretical distribution of ε_z in bore-expanding may provide the best for with the experimental data, because the ε_z distribution is more sensitive to yield characteristics than that of ε_θ . The experimental values of ε_z at the (do) larger than 12mm are lowered due to the effect of the punch corner shown in Fig.5. From this figure it can be seen that the experimental ε_z near the punch corner is much less than excepted theoritcally in the case of Brass sheet.

Fig.6 illustrates the comparison between the theoretical and experimental results of strain distribution in bore-expanding for the investigated materials, where the theoretical curves based on **Bassani** and **Hill's old** criteria are shown. The experimental values for thickness strain were averaged in the three directions. Both ε_θ and ε_z distributions calculated with **Bassani** criterion were satisfactorily fitted with the experimental except for the region near the punch corner, and the calculation predicting maximum thinning outside a hole edge. Same results were confirmed for the other metals.

Necking followed by fracture during bore-expanding occurred in the direction peculiar to the investigated materials, at 45° to the rolling direction in the case of **Al-Killed** steel and EG-low carbon steel but 0° in the **Brass 70/30**. The appearance around the hole edge is shown in Fig.7. The bore-expanding operation was stopped just after the necking initiation, and the radial distribution of ε_z was measured around the necked region. The result is shown in Fig.8, where the maximum thinning is again observed at a radius peculiar to the metals.

CONCLUSIONS

Throughout the experimental and theoretical investigation and based on the results obtained, the following conclusions can be drawn,

1. The bore-expanding limit defined as a starting point of the localized neck is less dependent on the hole diameter measured by the conventional visual method.
2. Bassani criterion was useful to predict the deformation and formability in bore-expanding test only at a certain value of r^* at $m^* < 2$ and $n^* > 2$ in all materials used.
3. Bassani criterion can predict the maximum thinning at a specific radial position outside the hole edge, which is encountered in the actual operation.

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Table: 1 Chemical composition of tested materials, (wt.%).

Materials	C	Mn	Cu	Zn	S	P	Si	Al	Fe
AL Killed Stell	0.10	0.38	-----	-----	0.03	0.03	0.28	0.19	rem
EG-Low Carbon Stell	0.13	0.43	-----	-----	0.06	0.07	-----	-----	rem
Brass 70/30	-----	-----	69.5	rem	-----	-----	-----	-----	0.01

Table: 2 Mechanical properties of tested materials and Bassani Parameters.

Materials	Direction with r.t.R.D.	$\sigma = K_o (\varepsilon + \varepsilon_o)^n$		Yield Stress (MPa)	U.T. stress (MPa)	Total elongation %	R	Bassani Parameters		
		n	K_o (MPa)					n*	m*	r*
	0°	0.24	612	182	320	38	1.70			
AL Killed Steel	45°	0.23	628	190	335	33	1.42	3.0	1.3	1.46
	90°	0.24	608	188	308	37	1.97			
	mean	0.24					1.63			
	0°	0.18	545	305	410	27	1.12			
EG-low carbon steel	45°	0.17	573	330	432	25	0.81	3.0	1.3	1.15
	90°	0.18	539	322	418	29	1.48			
	mean	0.18					1.06			
	0°	0.46	489	100**	256	42	0.91			
Brass 70/30	45°	0.47	472	91**	239	44	0.96	2.7	1.1	0.89
	90°	0.49	480	97**	249	46	0.99			
	mean	0.47					0.96			

** Proof Stress

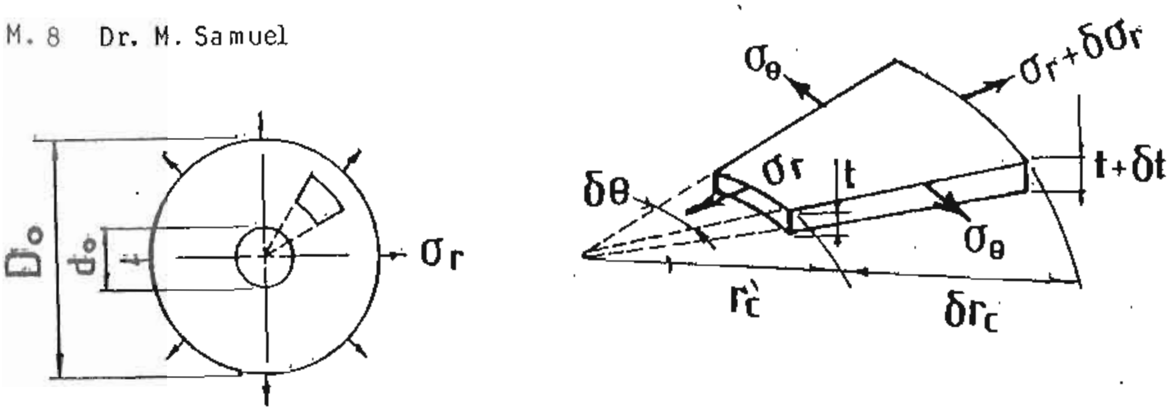


Fig. 1 Stress analysis of bore-expanding model.

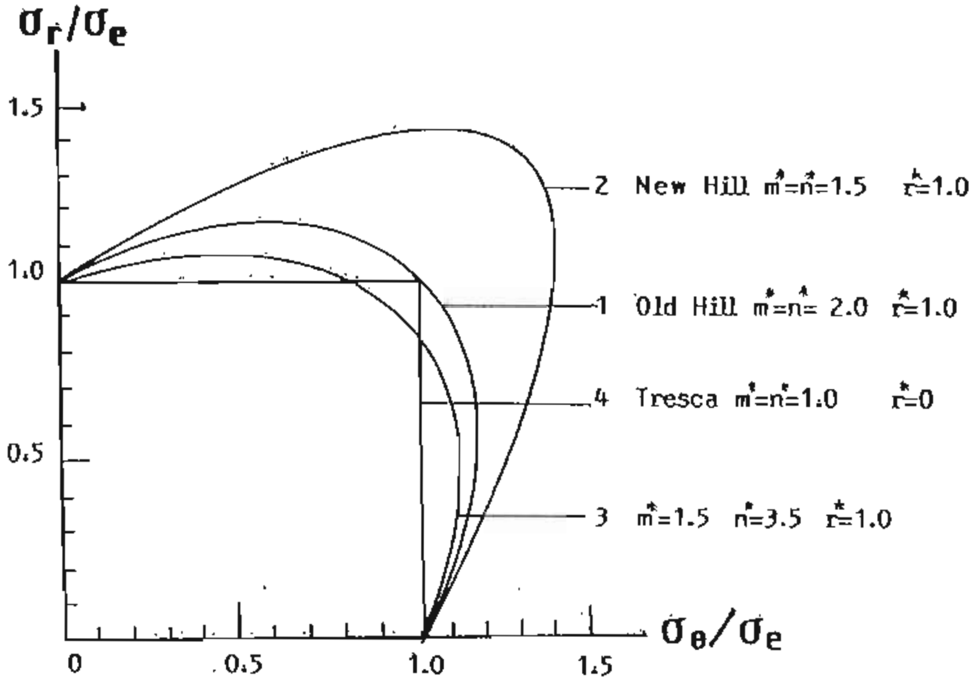


Fig. 2: Representation yield loci at different yield critirion.

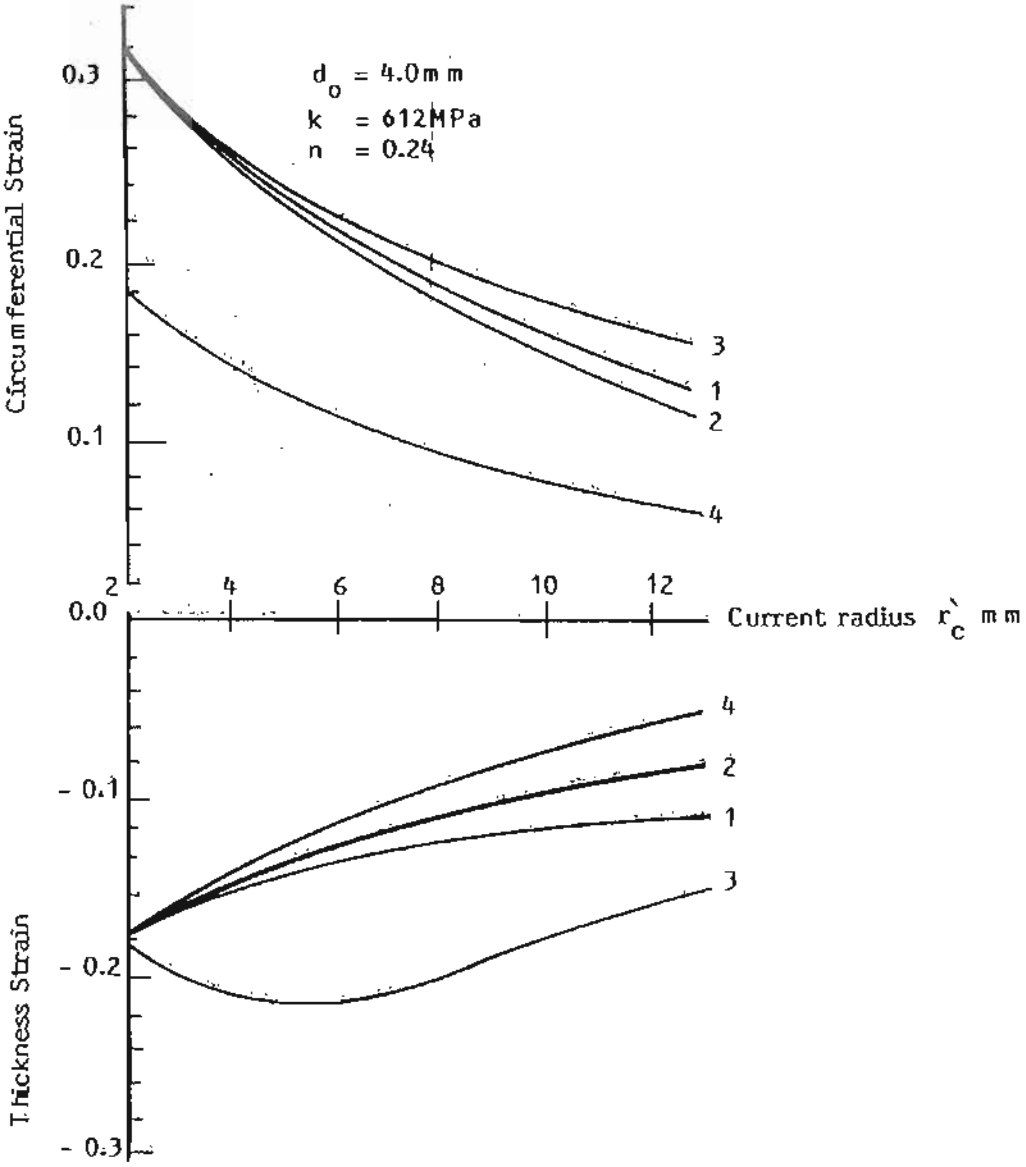
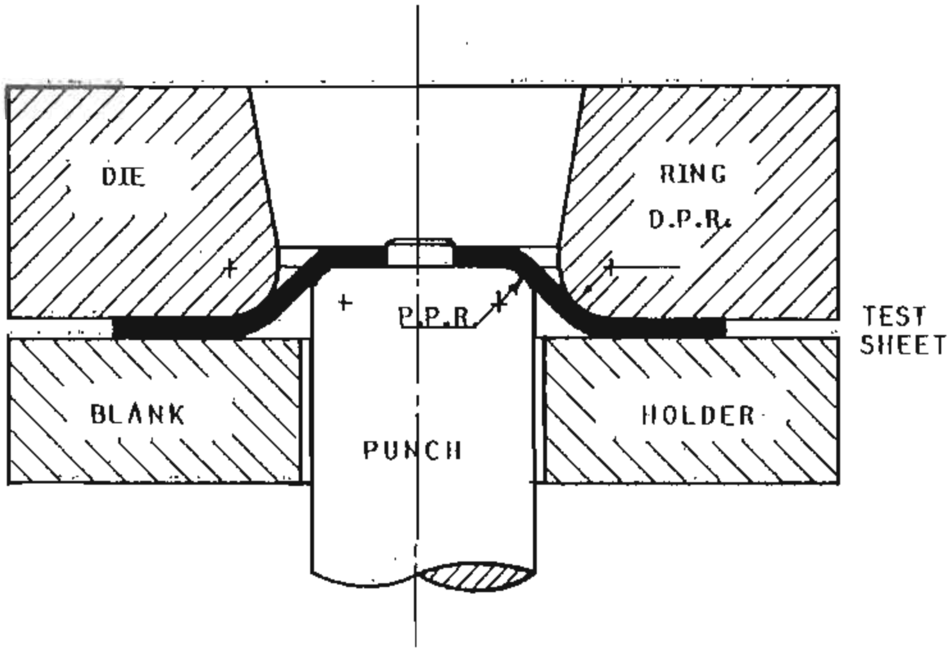


Fig. 3 Theoretical distribution of radial and thickness strains.



The Conditions of the are as follows:

Punch diameter	30 mm
Nose radius (P.P.R.)	5 mm
Die diameter	33 mm
Die profile radius (D.P.R.)	7 mm
Hold-down pressure	10 KN (Al-Killed Sted) 9.7 KN (Low Carbon St.) 6.5 KN (Brass 70/30)
Test-Blank dimensions	Outer diameter (Do = 100 mm) hole diameter (do = 4 , 6 , 8 , 10 , 12 and 14) mm.

Fig. 4 Geometry of BORE-EXPANTION formability test-rig.

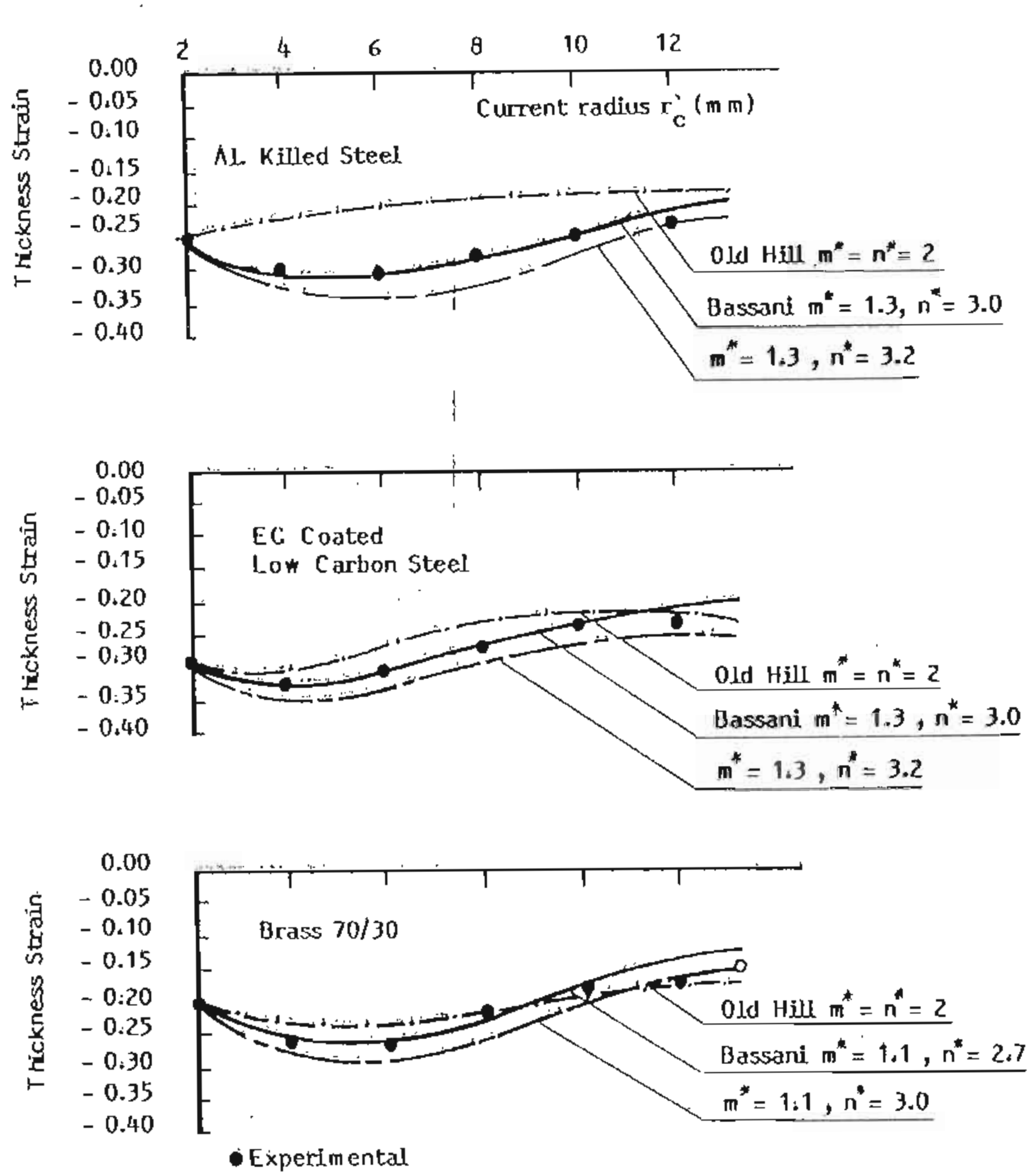


Fig. 5 Representative for determination of bassani criteria.

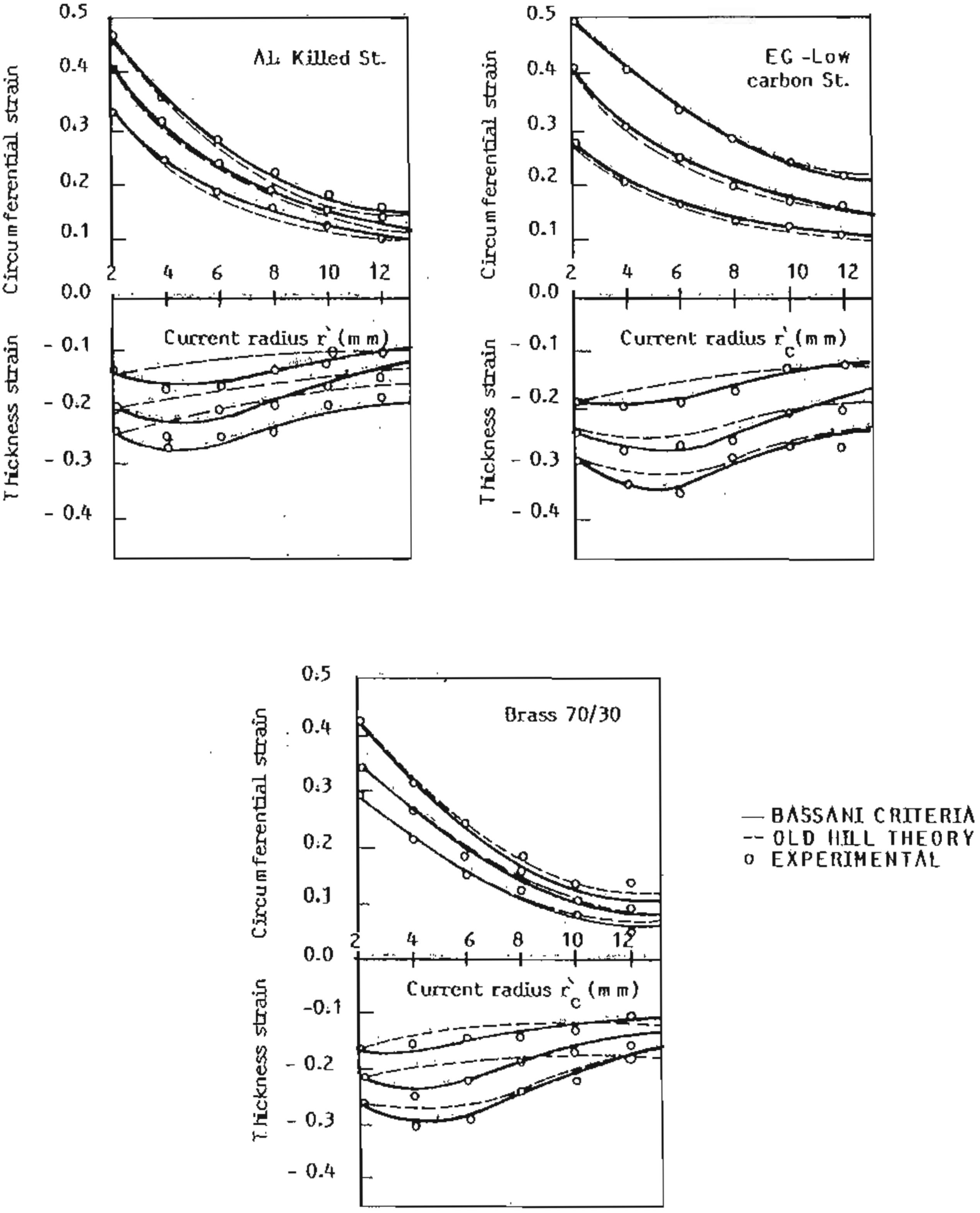
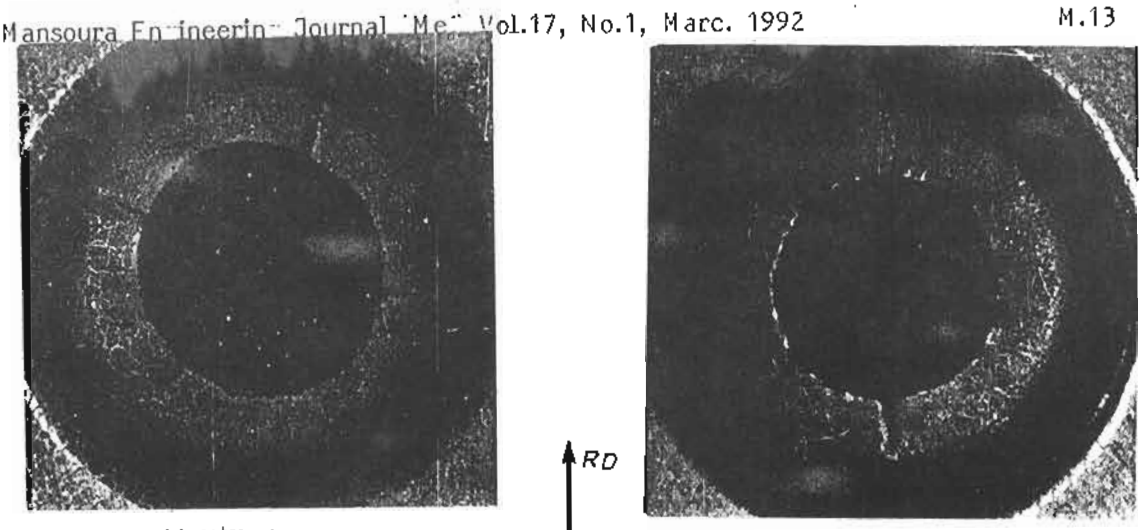
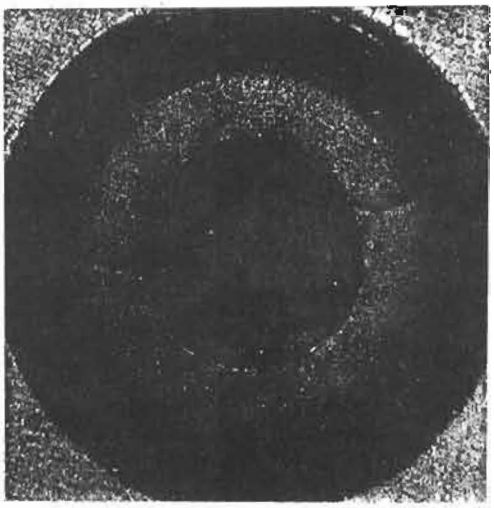


Fig. 6 Comparison between theoritcal and experimental results of strain distribution.



Al-Killed steel EG-Low Carbon Steel



Brass 70/30

Fig. 7 Observation of fractured areas around hole edge.

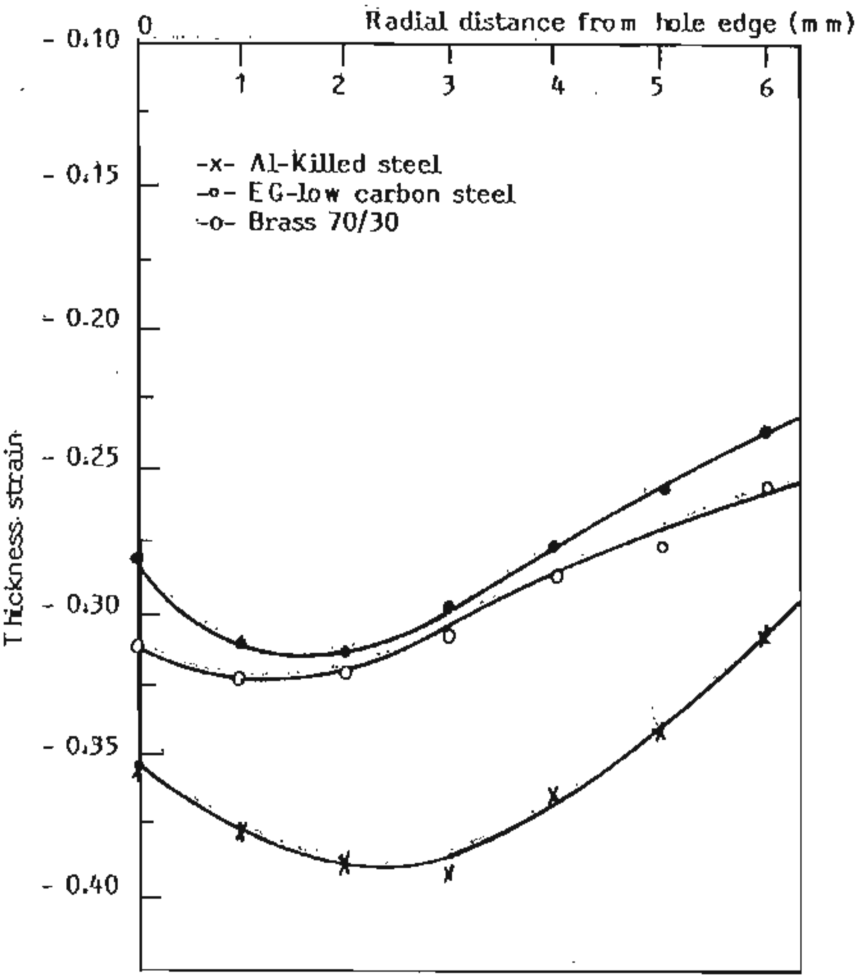


Fig. 8 Thickness strain distribution around hole edge at necking area.