Journal of University of Science and Technology Beijing
1994, Vol 1, No 1 ~ 2 : 70 ~ 75

Analysis of Sheet Metal Stress-strain Relations in Uniaxial and Biaxial Tension

Deng Zhi   Wang Xianjin
Faculty of Metal Forming, USTB, Beijing, 100083, PRC

ABSTRACT In this paper, sheet metal stress-strain relations in uniaxial and biaxial tension were theoretially and experimentally investigated. The interrelation of two *n* values respectively derived from uniaxial and biaxial tension test and their suitness for predicting sheet metal forming limits were given. The stress-strain relations of studied materials in uniaxial and biaxial tension were also used to analyse and calculate sheet metal deep-drawing process and its forming parameters. The results showed that the stress-strain relation under uniaxial tension stress state is more suitable to analyse sheet metal deep-drawing process.

KEY WORDS sheet metal forming, stress-strain relation, deep-drawing

The investigating results in the past have proved that if the loading process of a material is stable, its stress-strain relation will be unique and independent on its deforming state. But most of the experimental results showed that the stress-strain curves of materials in biaxial tension are always higher than that in uniaxial tension due to the limits of the experimental conditions and the uncontinuity and inhomogeneity of sheet metals. This phenomenon pointed out that the deforming states of materials have some influences on the stress-strain relations of materials. The deforming states in sheet metal forming are various, and the same material can display the different formability under the different deforming states. Consequently, in the analysises and calculations of sheet metal forming process and forming limits, it is necessary to investigate the selection of stress-strain relation and the interrelation of basic property parameters and formability of materials.

In this paper, sheet metal stress-strain relations in uniaxial and biaxial tension have been investigated experimentally. The interrelation of two *n* values respectively derived from uniaxial and biaxial tension test and their suitness for predicting sheet metal forming limits have been analysed theoretically. On the

Received 1994-05-10

other hand, the stress – strain relations of studied materials in uniaxial and biaxial tension have been respectively used to analyse sheet metal deep – drawing process and its forming limit parameters in order to look into the effects of the stress – strain relations in uniaxial and biaxial tension on assessing sheet metal formability.

1 Expermental Investigation

The materials used in uniaxial and biaxial tension test were 08 Al – killed steel, 20#, SPCEN, SPCE, 1Cr18Ni9Ti, 00Cr17Ni14Mo2, pure aluminium and stainless aluminium alloy. The materials used in Swift cupping test were made at 0 °, 45 °, 90 ° to the rolling direction. Three specimens were made at each direction and the experimental results were the average of them. The shape and dimension of a specimen were selected according to standard ASTME 517.

Biaxial tension test was carried out on a BHB – 80 hydraulic bulge testing machine. Three specimens of each material were made and the experimental results were the average of them. Figs. 1 and 2 show the experimental stress – strain curves of typical studied materials in uniaxial and biaxial tension, respectively.

Swift cupping test was carried out on a ZDM – 50T material testing machine. The experimental conditions and the dimensions of die and punch were selected in accordance with standard IDDRG. The bland – holding force Q was calculated according to the formula as below:

$$Q = 0.1 \times (1 - 18\beta/(\beta - 1) \cdot t_0/D_0) \cdot \beta^2 \cdot P_m \quad (1)$$

where $\beta = D_0/d_1$, D_0 is the diameter of a specimen, t_0 is the thickness of a specimen, d_1 is

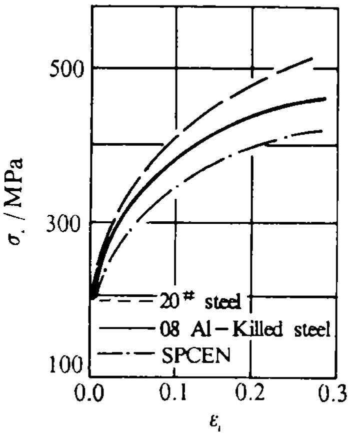

Fig.1 The stress – strain curves of studied materials in uniaxial tension

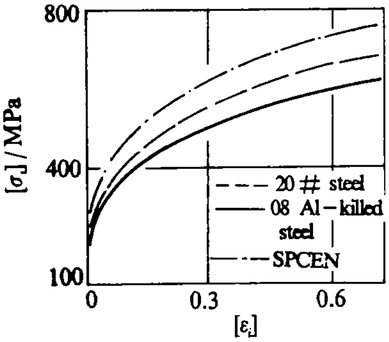

Fig.2 The stress – strain curves of studied materials in equal biaxial tension

the diameter of a drawing punch and P_m is the maximum punch load in some limit drawing ratio.

2 Analyses and Discussions

2.1 The interrelation of two *n* values in uniaxial and biaxial tension

In accordance with the stress−strain curve in biaxial tension test, [*n*] value under equal biaxial tension stress state could be obtained by the same method as determining *n* value under uniaxial tension stress state. The comparisons between [*n*] and *n* values of some studied materials in uniaxial and biaxial tension are listed in Table 1. Many investigations had been carried out in order to get the knowledge about the relation of *n* value under uniaxial tension stress state and the modelling formability of material. But few investigations had been made on the relation of [*n*] value under equal biaxial tension stress state and the modelling formability of material. However, most of stress states in sheet metal forming are biaxial tension, [*n*] value in biaxial tension test is more suitable for assessing the bulging formability of material.

Table 1 The comparisons of *n* and [*n*] value of the different materials

Materials	20# steel (1.07 mm)	Stainless Aluminium Alloy (1.00 mm)	1Cr18−Ni9Ti (1.00 mm)	00Cr17−Ni14Mo2 (1.00 mm)	Pure Aluminium (1.00 mm)	08Al −kill steel (1.02 mm)	SPCEN (1.00 mm)	SPCE (1.00 mm)
n	0.235	0.210	0.284	0.277	0.257	0.205	0.212	0.246
[*n*]	0.255	0.154	0.379	0.333	0.243	0.252	0.241	0.324

The physical significance of *n* value of material in uniaxial tension is definited and stands for the limit deformation of material in uniaxial tension. But [*n*] value of material in equal biaxial tension is not equal to the limit deformation of material in biaxial tension. Consequently, it is very important to investigate further the physical significance and law of [*n*] value. Compared *n* with [*n*] values of the different materials in Table 1, it is found for pure aluminium and stainless aluminium alloy [*n*] values are smaller than *n* values of same materials, and [*n*] values of other materials are larger than *n* values of same materials. This difference shows the influence of different stress states on the deforming behaviour of materials. From the interrelation analysis of [*n*] and *n* value, it can be found that the liner interrelation coefficient of [*n*] and *n* values of studied materials is 0.798. It confirms the fact that [*n*] and *n* values of the same material have not definite interrelation, and [n] and n values stand for different physical significance, respectively.

2.2 Stress – strain relation and the critical fracture load in deep – drawing process

In order to understand the effect of stress – strain relation of material under the different stress states on the calculations of the limit forming parameters in deep – drawing process, the determination of the critical fracture load in deep – drawing process had been studied. Reference [1] gives the critical fracture load formula in deep – drawing process as belows:

$$P_{cr} = 2\pi r_1 t_0 A C_1[(1+r)/(1+2r)^{1/2}]^{1+n} \cdot (n/\mathrm{e})^n \tag{2}$$

where $C_1 = 1/(1+r) \cdot (1+r+\mathrm{t}r'_p/2r_1r_p)/(1+tr'_p/2r_1r_p+tr'_1/2r_1r'_p)$, $t = t_0\mathrm{e}^{-n}$, $r'_p = r_p + t/2$, $t'_1 = r_1 + t/2$. Here, r_1 and r_p are punch and punch profile radius respectively, and r is plastic strain ratio, t_0 and t are the initial and current thickness of material, respectively. A, n are constants in the empirical stress – strain relation .

The empirical stress – strain relation under uniaxial and equal biaxial tension stress state were respectively used in the formula (2) to calculate the critical fracture load P_{cr} in deep – drawing process. Table 2 is the comparisons of the experimental and the calculating results of P_{cr} , and the experimental results of P_{cr} were obtained from Swift cupping test. It can be found from Table 2 that when the empirical stress – strain relations in equal biaxial tension were used in the formula (2), the error of the calculating and experimental results of P_{cr} is large except for 20# steel. The errors of SPCEN and 08 Al – killed steel are 15.7% and 6.9%, respectively, and the errors reduce to 0.2% and 4.4% respectively when the empirical stress – strain relations in uniaxial tension were used in the formula (2). It is shown that the stress – strain relation in uniaxial tension is more suitable to calculate theoretically the critical fracture load in sheet metal deep – drawing process.

Table 2 The comparison of the calculating and experimental results of the critical fracture load P_{cr} ($r_1 = 25.0$ mm, $r_p = 5.0$ mm)

Material	Experimental results of P_{cr} /kN	Stress – strain relation in uniaxial tension			Stress – strain relation in equal biaxial tension		
		A /MPa	n	Calculating results of P_{cr} /kN	[A] /MPa	[n]	Calculating results of P_{cr} /kN
08 Al – killed steel (1.02 mm)	6 961.57	60.947	0.205	6 654.44	62.858	0.252	6 482.99
20# steel (1.07 mm)	8 057.30	70.045	0.235	7 367.56	73.456	0.255	7 546.67
SPCEN (1.00 mm)	6 529.88	55.924	0.212	6 516.87	67.020	0.241	7 555.47

2.3 The use of the stress – strain relations under the different stress states in sheet metal deep – drawing process analysis

Reference [2] developed a new comprehensive general computer model for sheet metal deep – drawing process. This model could be used to obtain the suitness of the stress – strain relations in uniaxial and biaxial tension for sheet metal deep – drawing process analysis. According to the general computer model, the maximum drawing force in deep – drawing process could be calculated. Fig.3 is the comparison of the calculating results which used the stress – strain relations in uniaxial and biaxial tension and the experimental results of the maximum drawing force in deep – drawing process. The comparisons confirm the fact that the stress – strain relation under uniaxial tension stress state is more suitable to be used in the force analysis of sheet metal deep – drawing process. Because the limit drawing ratio depends on the critical fracture load and the maximum drawing force in deep – drawing process, the stress – strain relation in uniaxial tension is also more suitable to be used in theoretical determining the limit drawing ratio. Fig. 4 shows the theoretical stress and strain distribution curves of a deep – drawing workpiece calculated according to the stress – strain relations under the different stress states (D_0, R in Fig. 4 are the initial and the current diameter of a deep – drawing workpiece, respectively) . Compared the calculating curves in two cases, it is known that when the stress – strain relation under the different stress states are used to analyse deep – drawing process, the variation of circumferential strain is small, the variations of thickness strain and radial stress are large so as to evidently effect the determinations of the drawing force and LDR. Therefore, the selection of the stress – strain relations is very important to analyse sheet metal deep – drawing process.

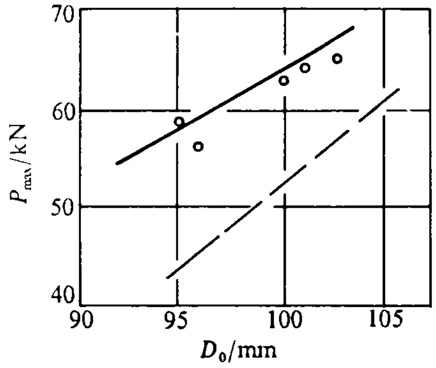

Fig. 3 The comparison of the calculating and experimental results of the maximum drawing force (08 Al – killed steel, $D_0 = 100.00$ mm, $t_0 = 1.02$ mm)

– – – The stress – strain relation in equal biaxial tension

—— The stress – strain relation in uniaxial tension

○ The experimental results

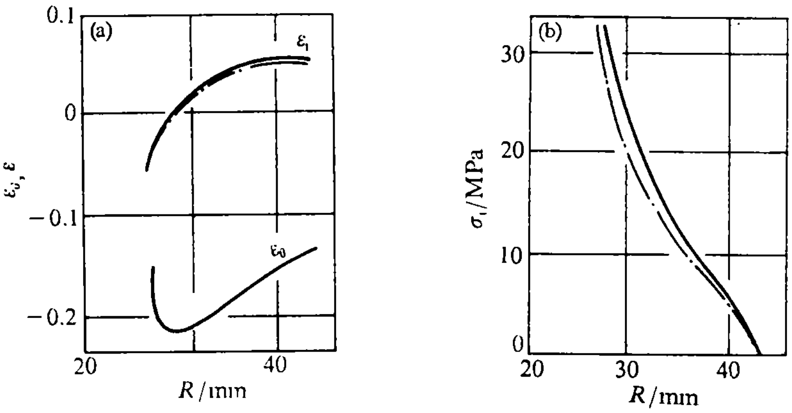

Fig.4 The theoretical stress and strain distributions of a deep−drawing workpiece
(08 Al−killed steel, $D_0 = 100.00$ mm, $t_0 = 1.02$ mm)

The investigations and results mentioned above were aimed at sheet metal deep−drawing process. It will be necessary to further investigate the effect of the stress−strain relations under uniaxial and equal biaxial tension stress state on other sheet metal forming processes.

3 Conclusions

(1) The strain−hardening exponent *n* and [*n*] values of materials in uniaxial and biaxial tension have a certain interrelation, but it has not a definite law. The stress−strain relations between uniaxial and biaxial tension display the different deforming laws of the same material.

(2) The stress−strain relation under uniaxial tension stress state is more suitable to analyse deep−drawing process and calculate the limit forming parameters.

References

1 Deng zhi, Chen Hezheng. Determination of the Critical Fracture Load and Limit Drawing Ratio of the Deep−drawing of Cylindrical Cups with Flat−nosed Punch (in Chinese). Journal of Tsinghua University, 1989, 29(2): 87 ~ 95

2 Deng Zhi, Chen Hezheng. Numerical Analysis of Sheet Metal Deep−drawing Process . Chinese Journal of Mechanical Engneering, 1989, 25(4) : 33 ~ 40

[*continued on page 89*]

2 Ramesh Bapu G. Electrodeposition of Zinc-Nickle Alloys. Metal Finishing, 1987, 85(2): 49 ~ 53

3 Benner A. , Electroplating of Alloys. New York and London: Academic Press, 1963.

4 Fudushima. et al. Mechanism of the Electrodeposition of Zn with Iron- Group Metals from Sulface baths. Surface Techniques of Metals, 1983, 33(11): 20 ~ 40

5 Imai Y, Kurachi M. Study of the Electrodeposition of Zn Alloys. Denki Kagaku. 1979, 47 (2): 89 ~ 94

6 Chassaing E, Wiarch. Electrocrystallization Mechanism of Zn-Ni Alloys in Choride Electrolytes. Electrochemic Acta, 1992, 37(3) : 545

7 Cao C N. On the Faradaic Admittance at Mixed Potential. J of Chinese Society of Corrosion and Protection, 1993, 13(2) : 91

氯化铵体系 Zn-Ni 合金电镀

吴继勋 刘永勤 卢燕平 孟惠民

北京科技大学表面科学与腐蚀工程系，北京 100083

摘 要 研究了镀液成分和工艺参数对镀层 Ni 含量的影响. 探讨了 Zn-Ni 合金共沉积机理，获得了耐蚀性为同等镀锌层 6 倍以上的光亮 Zn-Ni(13%) 合金电镀的配方和工艺条件.

关键词 电镀，氯化铵，Zn-Ni 合金

中图分类号 TG174.441

[*continued from page 75*]

薄板单向拉伸与双向拉伸应力应变关系分析

邓 陟 王先进

北京科技大学金属压力加工系，北京 100083

摘 要 本文对金属薄板在单向拉伸和双向拉伸状态下的应力应变关系进行了理论和实验研究，给出了两种应力状态下所得 n 值的相关性， 分析了其预报成形极限的适用性. 将研究材料在单向及双向拉伸试验中所获应力应变关系用于拉延成形的过程分析和极限成形参数计算，结果表明，单向拉伸时的应力应变关系用分析拉延成形过程更为符合实验结果.

关键词 薄板成形，应力应变关系，拉延成形

中图分类号 TG386.32, TG386.41