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Short Communication

OVERVIEW AND ASSESSMENT OF FORMABILITY EFFECT OF MATERIAL PROPERTIES OF SHEET METAL - A SHORT COMMUNICATION

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ABSTRACT

Metal forming is the backbone of modern manufacturing industry besides being a majorindustry in itself. Throughout the world hundreds of million tons of metals go through metalforming processes every year. As much as 15–20% of GDP of industrialized nations comes frommetal forming industry.The industrial metal working process of sheet metal forming is strongly dependenton numerous interactive variables: material behaviour, lubrication, forming equipment. The quality of a stamped commercial part is largely influenced by the material flowwithin the tools during the sheet metal forming operation. Therefore it is important tocontrol the material flow rate to avoid defects such as wrinkling, tearing, surface distortion and springback. This paper presents an outline of published test methods for determination mechanical properties of steel sheet that influence it's forming characteristics either directly or indirectly, can be measured by uniaxial tensile test. The tensile test results of particular test include the yield strength, ultimate tensile strength, plastic strain ratio, planar anisotropy, strain hardening exponent and strength coefficient.Testing of sheet metal formability has been a long-standing challenge becausevariability in test procedures and testing machines can mask material variations. Inspite of the importance of such testing for manufacturing, few standards exist. Uniaxial tensile stress may be made with specimens obtained from longitudinal, diagonal and transverse relative directions to rolling direction. This review deals with how to determine the important value of formability strain rate coefficient n, Lankford anisotropy coefficient r, Lube and Blank location have the strongest influences on formability. Among these, the effect of anisotropy is most important.

INTRODUCTION

Sheet Metal Formability

Formability refers to the ability of sheet metal to be formed into a desired shape without necking or cracking. Necking is localized thinning of the metal that is greater than the thinning of the surrounding metal. Necking precedes cracking. From the metallurgical perspective, the formability of a particular metal depends on the metal's elongation, which is the total amount of strain measured during tensile testing. A metal with a large elongation has good formability because the metal is able to undergo a large amount of strain (work) hardening.

Anisotropy and the Lankford Coefficient

Anisotropy is defined as the directionality of properties and it is associated with thevariance of atomic or ionic spacing within crystallographic directions (Callister, 1997). For single crystals it can be the variation of properties (like the

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electricalconductivity, the elastic modulus, the index of refraction, etc.) in differentcrystallographic directions. (Callister, 1997) Points that the extent and magnitude ofanisotropic effects in crystalline materials are functions of the symmetry of thecrystal structure. Since common engineering materials are polycrystalline, thecrystallographic orientations of the individual grains are totally random, if completere-crystallization has taken place. Although all grains have certain anisotropy, theoverall structure will behave isotropically, since the anisotropy effect is averagedout. However if the materials are deformed for instance with no complete recovery,the crystal grains are oriented in deformation specific directions, making thematerial anisotropic. During deformations, the crystal lattices rotate and they affect the plastic properties (Hosford and Caddell, 2007). The anisotropy coefficient or the Lankford coefficient (Lankford, *et al*., 1950) is a measure of anisotropy. This parameter can be called as the'resistance to thickness change'. This coefficient is defined as

$$r = \frac{\varepsilon_2}{\varepsilon_3}$$

Where ε_2 and ε_3 are the strains in the width and thickness directions

For a successful sheet metal stamping, the normal anisotropy must be as large aspossible whereas the planar anisotropy must be as small as possible. (Weilong and Wang, 2002) indicate when the r-value of sheet metals is greater, the thinning should be smaller and thus the formability is better. However, a greater r-value does not satisfy all sheet metal forming processes such as necking and bending, meaning that each forming process should have individual forming properties related to the anisotropy of the materials, and the different strain states would cause different forming failures (Hosford and Ducan, 1999). The Lankford anisotropy coefficient depends on the in-plane direction. In orthogonal anisotropy three r-values are determined: Along the rolling direction (RD), along 45° to RD and perpendicular to rolling direction (transverse direction, TD). These values are denoted as r0, r45, and r90 respectively.The average of these r-values in the plane of the sheet metal represents the coefficient of normal anisotropy r_n. The coefficient of normal anisotropy is obtainedfrom equation given below (Banabic, *et al*., 2000).

$$r_n = \frac{r_0 + 2\gamma r_{45} + r_{90}}{4}$$

`thinning during a deep drawingoperation than a material having a smaller r_n value, provided that their flowcharacteristics are identical. For instance, aluminium usually has an r value smallerthan 1 (about 0.6), whereas steel has a r_n value larger than 1 (about 1.5). In thepresent study, the investigated aluminium material (6111-T4) has a normalanisotropy value of 0.694, whereas the steel material (DDQ mild steel) has 2.012 (Table 1).

DISCUSSION

In the study of (Weilong and Wang, 2002) it is shown that although materials having greater r -values are more suitable for deep drawing, their deformation resistance isalso increased with increasing r-values. It was stated by (Marciniak, *et al*., 2002) that for materials having a normal anisotropy value larger than unity, widthstrain is greater than the thickness strain in the tensile test; which is associated witha greater strength in the through-thickness direction, and generally a resistance tothinning. A high r_n value allows deeper parts to be drawn and in shallow, smoothlycontouredparts (like automobile panels) a high value may reduce the chance ofwrinkling or ripples in the part (Marciniak, *et al*., 2002). (Weilong and Wang, 2002) suggest that for a deep drawing operation, a suitable material must have an r-value, which is larger than unity.

$$\Delta r = \frac{r_0 + r_{90} - 2\gamma r_{45}}{2}$$

A measure of the variation of normal anisotropy with the angle to the rollingdirection is given by the quantity Δr, known as planar anisotropy.

Yield Strength

Yield strength production variation varies with the mill and processor:chemistry, mechanical processing and annealing and the range suppliers

Table 1. Detailed information about the material properties is given.

Materials	K [MPa]	n	R_0	R_{45}	R_{90}	Δr	r_n
6111-T4	538.225	0.2255	0.894	0.611	0.660	0.083	0.694
DDQ mild Steel	547.763	0.2692	2.160	1.611	2.665	0.401	2.012
Materials	**ρ [g/mm³]**	**v**	ε_0	**E [GPa]**	σ_y **[MPa]**	**% Elongation Total**	
6111-T4	2.6	0.3395	0.00256	70.725	180.825	27.350	
DDQ mild Steel	7.8	0.3	0.00088	221.368	193.918	48.069	

normal distribution or ± 20 MPa, high influence on hardening behaviour, yield surface, effectiveness of beads and pads, springback (Marciniak, *et al*., 2002).

Tensile Strength

Tensile strength variable with chemistry and mechanical processing and the range suppliers normal distribution or ± 20 MPa, influence hardening with yield (Marciniak, *et al*., 2002).

Strain Hardening Exponent (N)

The input of N value for which the production variation varies with chemistry, mechanical processing, and annealing and the range fluctuates with variation of yield and tensile strength and effect of hardening behaviour, forming limit (Marciniak, *et al*., 2002).

Plastic Strain Ratio (R)

The input of R value for which the production variation varies with hot roll vs cold roll, mechanical, coil rolling direction and the range is ± 20 (steel), ± 10 (aluminium), influence yield surface, strain/stress distribution (Marciniak, *et al*., 2002).

Effect of Anisotropy in Drawing

The plastic flow behaviors of these two materials are nearly identical as far as the flow curve is concerned; the difference in product properties arises therefore from the differences in anisotropy and elastic properties (Fig. 1).

Additionally, the anisotropy constants (strain ratios at three different angles trolling direction) of the two materials show (that their anisotropic behaviors are entirely different. This difference in anisotropy is also an important reason for differences in product shapes and qualities. The effect of anisotropy is inspected within this benchmark (Fig. 2).

Plastic Tensile Instability and Necking

The forming limit diagram (FLD) (also known as the forming limit curve, FLC) is another important

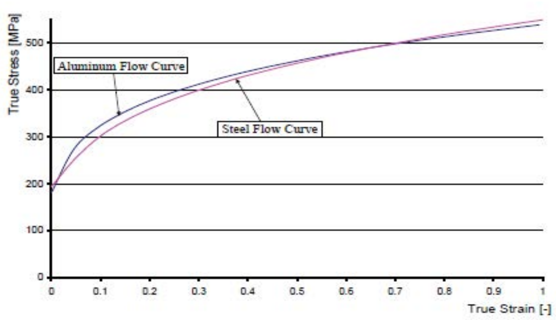

Fig. 1 Flow curves of 6111-T4 aluminum and DDQ mild steel.

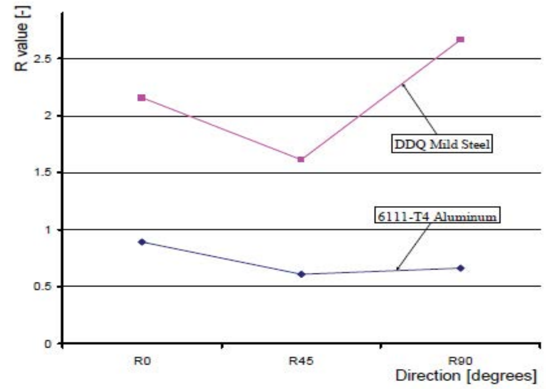

Fig. 2 R-values of 6111-T4 aluminum and DDQ mild steel.

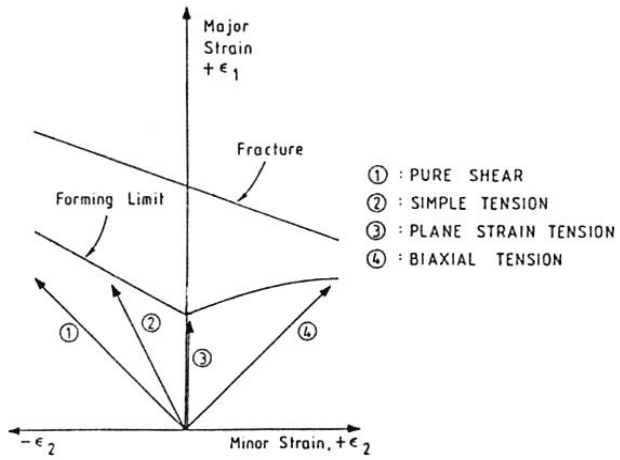

Fig. 3 The forming limit diagram – loading types.

concept utilized for the evaluation of the formability of sheet metals. By the use of these diagrams, the onset of failure due to local necking, or potential trouble areas on the deformed part under various loading types can be estimated and investigated The research in this field was pioneered by (Keeler and Backofen, 1963) based on the observations of (Gensamer, 1946). Maximum values of principal strains ε_1 and ε_2 can be determined by measuring the strains at fracture on sheet components covered 20 with grids of circles. The most widely used technique involves printing or etching a grid of small with constant diameter on the metal sheet before forming. During forming the initial circles of the grid distort and become ellipses. From the minor and minor axes of these ellipses, the principal strains on sheet specimens can be determined. Keeler plotted the maximum principal strain against the minimum principal strain obtained from such ellipses at fracture of parts after biaxial stretching. This way, a curve limiting the tolerable range is obtained (Fig. 3).

Later, (Goodwin, 1968) plotted the curve for tension/compression domain by using different mechanical tests. In this case, transverse compression allows

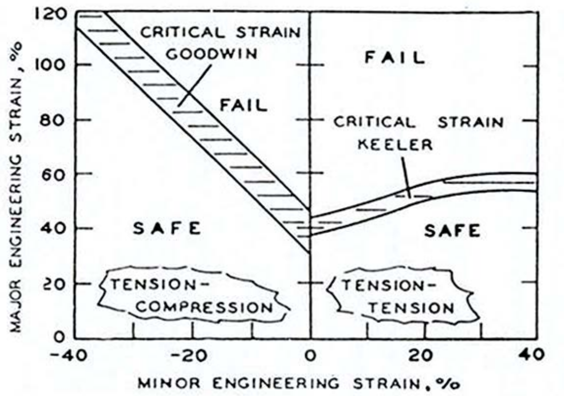

Fig. 4 Keeler – Goodwin diagram (FLD).

for obtaining high values of tensile strains like in rolling or wire drawing. The diagrams of Keeler and Goodwin together give the values of ε_1 and ε_2 at fracture. This currently is called the forming limit diagram, sometimes also as the Keeler – Goodwin (Fig. 4) indicated that from subsequent experimental and theoretical research, two more types of FLD's have emerged (Banabic, *et al*., 2000): the wrinkling limit diagram and the limit stress diagram. There are various tests to determine the FLD experimentally (Banabic, *et al*., 2000) like the uniaxial tensile test, hydraulic bulge test, punchstretching test, Keeler test, Hecker test, Marciniak test, Nakazima test and Hasektest. From these, Marciniak test or hydraulic bulge test is utilized for eliminating friction effects; uniaxial test is preferred for its simplicity and Nakazima test is suitable since it is capable of covering a great variety of strain paths. It was stated by (Banabic, *et al*., 2000) that there are various models present for the calculation of FLD's. The first ones were proposed by Swift and Hill utilizing the models of diffuse necking and localized necking respectively

Instability

Different (Hosford and Caddell, 2007) said phenomena limit the extent to which a metal may be deformed. Buckling may occur under compressive loading if the ratio of height-to-diameter is too great. Fracture may occur under tension called plastic instability. When a structure is deformed, there is often a maximum force or maximum pressure after which deformation continues at decreasing loads or pressures. It is assumed throughout this chapter that the strain hardening is described by $\bar{\sigma} = K\varepsilon^{-2}$. If other expressions better represent the behaviour, they can be used with the same procedures. Solutions for effective strain at instability are functions of n.

Variation of Necking Limits with Strain Ratio

Selected theoretical results for limit strains are presented in (Fig. 5-7) (Mellor, 1956; Swift, 1952) for different material characteristics.In each case the depth of the incipient groove at instability has been assumed to be equal to the surface roughness depth R, existing at that point. The Swift instability curves are included in these Figurers in order to give a feeling for the level of straining. Results are plotted for different ratios of to do and it can be noted that a ratio of about 30 is typical of many commercial sheet metals. The assumed material constants in (Fig. 5) are characteristic of an isotropic steel sheet, in (Fig. 6). of aluminium and in (Fig. 7). of 70130 brass. The results are consistent with experimental observations that the limit strains decrease as the sheet thickness decreases. It is clear from (Fig. 5-7) that the k-value exerts aconsiderable influence on the limit strains and when k = 2 (Fig. 7), the plotted

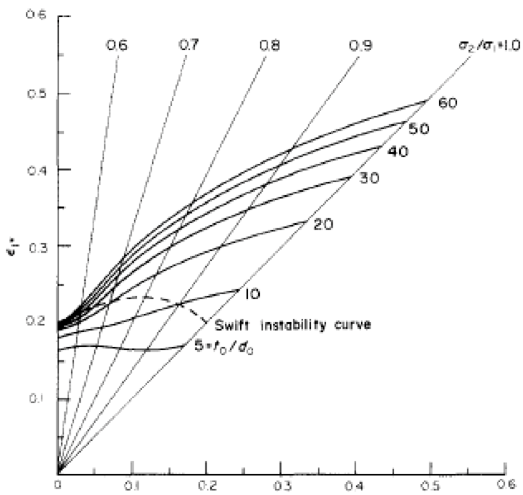

Fig. 5 Variation of limit strains with thickness to grain ratio, n=0.2, k=1.0, $R_0 / T_0 = 0.0015$.

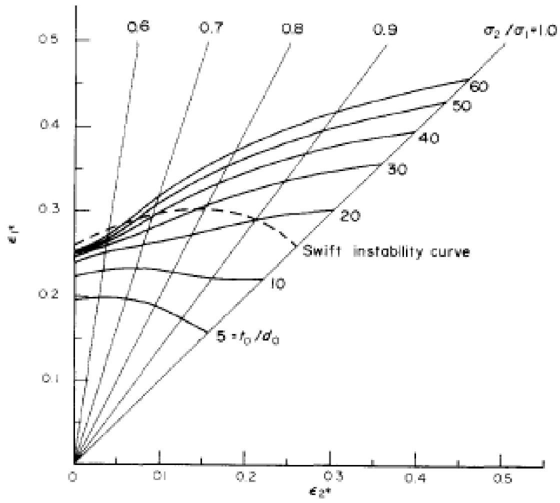

Fig. 6 Variation of limit strains with thickness to grain ratio[22], n=0.26, k=1.4, $R_0 / T_0 = 0.0015$.

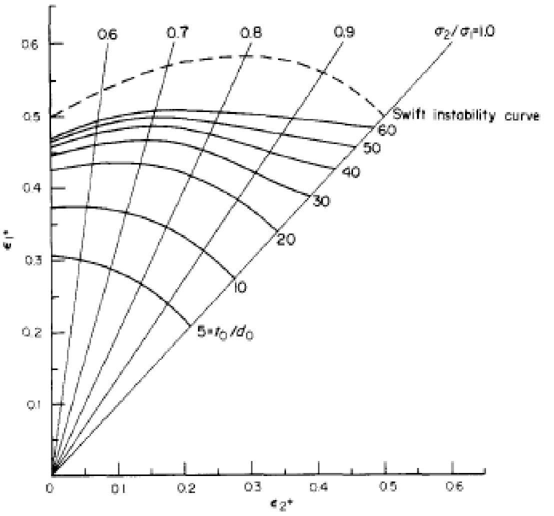

Fig. 7 Variation of limit strains with thickness to grain ratio[22], n=0.5, k=2.0, $R_0 / T_0 = 0.0015$.

limit strains are all less thanthe Swift instability strains. This last result might seem surprising but it is consistent with experimental.

Results reported by Azrin and Backofen." It is also interesting to note that Mellor found that a diaphragm of annealed 70/30 brass, deformed by hydrostatic pressure, fractured without exhibiting a classical instability condition. The effect of reducing the incipient groove depth from R to R/2, where ε_{1*} / n is plotted against to do. The limit strains are, of course, increased by reducing the assumed incipient groove depth and the effect is proportionately greater as k decreases. The Swift instability strain is represented on this (Fig. 7), by a value of ε^* / n equal to unity.

The general material characteristics that influence the outcome of a sheet metalforming process are the following (Marciniak, *et al.*, 2002).

Strain Hardening of the Sheet

The greater the strain-hardening of the sheet, the better it will perform inprocesses where here is considerable stretching; the straining will be more uniformly distributed, and the sheet will resist tearing when strain-hardeningis high. Additionally, since necking failures are associated with the strainhardening coefficient n, materials having higher n will generally exhibit better formability (Beddoes and Bibby, 1992).

Initial Yield Strength

It is related to the strength of the formed part. Although for light weight materials, higher yield strengths are preferable, such materials are harder toform and combined with low elastic moduli, it induces increased springback problems (Sönmez, 2005; Sivam, *et al.*, 2016; Sivam, *et al.*, 2015; Sivam, *et al.*, 2016).

Elastic Modulus

A higher modulus will give a stiffer component, whereas a lower modulusgives larger springback (Marciniak, *et al.*, 2002).

Total Elongation

It is the amount of uniaxial strain at fracture it includes both elastic and plastic deformation and is commonly reported as percent elongation at fracture. Percent elongation = (elongation at rupture) x 100/ (initial gage length).

Anisotropy

If the magnitude of the planar anisotropy parameter, _R, is large, either, positive ornegative, the orientation of the sheet with respect to the die or the part to be formed willbe important; in circular parts, asymmetric forming will be observed. If thenormal anisotropy ratio R is greater than unity it indicates that in the tensile test the widthstrain is greater than the thickness strain; this may be associated with a greater strength inthe through-thickness direction and, generally, a resistance to thinning. Normal anisotropy R also has more subtle effects. In drawing deep parts, a high value allows deeper parts tobe drawn. In shallow, smoothly-contoured parts such as autobody outer panels, a highervalue of R may reduce the chance of wrinkling or ripples in the part. Other factors suchas inclusions, surface topography, or fracture properties may also vary with orientation;these would not be indicated by the R-value which is determined from plastic properties (Marciniak, *et al.*, 2002).

Fracture

Even in ductile materials, tensile processes can be limited by sudden fracture. The fracturecharacteristic is not given by total elongation but is indicated by the cross-sectional area ofthe fracture surface after the test-piece has necked and failed. This is difficult to measurein thin sheet and consequently problems due to fracture may not be properly recognized (Marciniak, *et al.*, 2002).

Homogeneity

Industrial sheet metal is never entirely homogeneous, nor free from local defects. Defectsmay be due to variations in composition, texture or thickness, or exist as point defects suchas inclusions. These are difficult to characterize precisely. Inhomogeneity is not indicatedby a single tensile test and even with repeated tests, the actual volume of material beingtested is small, and non-uniformities may not be adequately identified (Marciniak, *et al*., 2002).

Surface Effects

The roughness of sheet and its interaction with lubricants and tooling surfaces will affectperformance in a forming operation but will not be measured in the tensile test. Specialtests exist to explore surface properties (Marciniak, *et al*., 2002).

Damage

During tensile plastic deformation, many materials suffer damage at the microstructural level. The rate at which this damage progresses, varies greatly with different materials. It may be indicated by a diminution in strain-hardening in the tensile test, but as the rate of damage accumulation depends on the stress state in the process, tensile data may not be indicative of damage in other stress states (Marciniak, *et al*., 2002).

Rate Sensitivity

As mentioned, the rate sensitivity of most sheet is small at room temperature; for steel itis slightly positive and for aluminium, zero or slightly negative. Positive rate sensitivity usually improves forming and has an effect similar to strain-hardening. As well as being indicated by the exponent m, it is also shown by the amount of extension in the tensile test-piece after maximum load and necking and before failure, i.e. ETotal − Eu, increases with increasing rate sensitivity (Marciniak, *et al*., 2002).

Sensitivity to Material Properties

It is widely understood that wrinkling of sheet metal is strongly influenced by the material properties (Ameziane-Hassani and Neale, 1991; Havránek, 1975; Lee, 1987; Logan and Hosford, 1985; Naziri and Pearce, 1968; Ni and Jhita, 1990; Saran, *et al*., 1990; Wang and Lee, 1989; Yoshida, 1997). Work hardening behaviour, strength coefficient andyield stress are among those that may have significant effects on the drawing process.Yield strength, S,, strength coefficient, K, and work hardening exponent, n, werevariedover a reasonable range of values, one at a time, while the other parameters were keptConstant. The true stress-strain curves produced based on different combinations of Kand n values are shown in (Fig. 8) below.

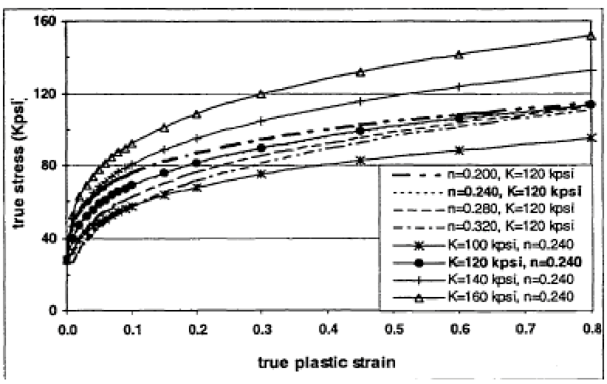

Fig. 8 True stress-strain curves for different combinations of strength coefficient, and work hardening exponent, n[12].

It can be seen from (Fig. 8) that the stress-strain curve moves downward withincreasing work hardening exponent, n. This corresponds to more plastic deformation ata given level of stress. In contrast, the stress-strain curve moves upward with increasingstrength coefficient, K. In a drawing process, the blank has more tendency to wrinklewhen the material has a greater resistance to plastic deformation. It cm therefore bepredicted thatmaterials with a high K value, and low n value will wrinkle more easily than materials with a low K value and high n value.

CONCLUSION

The assessment of formability effect of material properties of sheet metal were made by using different material and anisotropy, strength of material, limit strain ratio were shown, material properties, and sensitivity of material were studied. The high r-value, which is effective in improving cup formability, and thanks to this, its limit-drawing ratio is higher for material formability. The strain at maximum stress and ultimate strain of the sheets increases as sheet thickness increases after which the strain values remain almost the same or slightly decrease. The yield strengths of sheets with different thicknesses to be correlated with the values of the ultimate strain and strain at maximum stress suggesting that the dependency of the strain values on sheet thickness might have to do with the rolling process used for the production of sheet metals. The minimum bending radius linearly increases as the sheet thickness increases. Unlike deep-drawing processes, the failure strain of sheets in air bending decreases as sheet thickness increases.

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