Analysis of Strain Non-uniformity Index (SNI) for Different Geometries of Drawn Sheet Metal Parts

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Abstract: This paper explores the effect of the part geometry on the variation of the Strain Non-Uniformity Index (SNI) at failure in shapes drawn from a single material. Forming of different shapes, namely, a square cup, an equibiaxially stretched sample was performed experimentally as well as simulated using AUTOFORM 5.2 Plus software. Failure predictions were made using the SNI based methodology and the FLD, and compared with experimental outcomes. Forming of the cross draw (FTF benchmark), was simulated and corresponding critical SNI was established based on the failure predicted with reference to the FLD. The SNI values so obtained are discussed in light of different component shapes and draw depths during forming of various geometries.

Keywords: - Forming Limit Diagram (FLD), Strain Non-Uniformity Index (SNI), sheet metal forming, Formability

1. Introduction

Strain distribution based failure criterion based on the Strain non-uniformity index (SNI) was proposed earlier by Date et. al. [1] and has been applied to failure predictions in drawn sheet metal parts [2]. Since the strain distribution and hence the SNI is an outcome of part geometry, forming conditions and material properties, this paper examines the effect of part geometry as well as the material geometry on the evolution of the SNI over the entire forming process.

$$\text{Strain Non-uniformity Index (SNI)} = \text{Peak thickness strain} - \text{Average thickness strain} \ldots\ldots\ldots\ldots \quad (1)$$

2. Work plan

In the present work, square cups of side 40mm were drawn from blanks of five different materials (four ferrous and one aluminium alloy), laser marked with circles of initial diameter of 2mm. Similarly, square blanks of side 200mm, and similar grid markings were stretched over a punch of diameter 100mm. Strain non-uniformity index (SNI) was determined based on the strain distribution taken along the diagonals for square cups and along meridians for the equibiaxially stretched sheets. SNI was also established using the strain distributions obtained from AUTOFORM simulations of different shapes, namely, square cup, equibiaxially stretched sheet, FTF Cross shape [3], FTF triangular shape, Jaguar land rover aluminium panel (Numisheet 2016 Benchmark -2) [4], and the kidney tray. In each case the evolution of the SNI with punch travel was plotted. The properties of materials used for experiments as well as for simulation are given in Table 1.

3. Results and Discussion

A good agreement with experiment, on the prediction of failure location using the FLD and the SNI based methodology is readily inferred from Fig. 1 and Fig. 2. The evolution of the SNI with punch travel for three different shapes is seen in Fig. 3 (a-c). It is found that the SNI variation with draw depth for five different materials lies in a narrow band for each of the shapes studied. Fig. 3d summarises the variation for different component geometries.

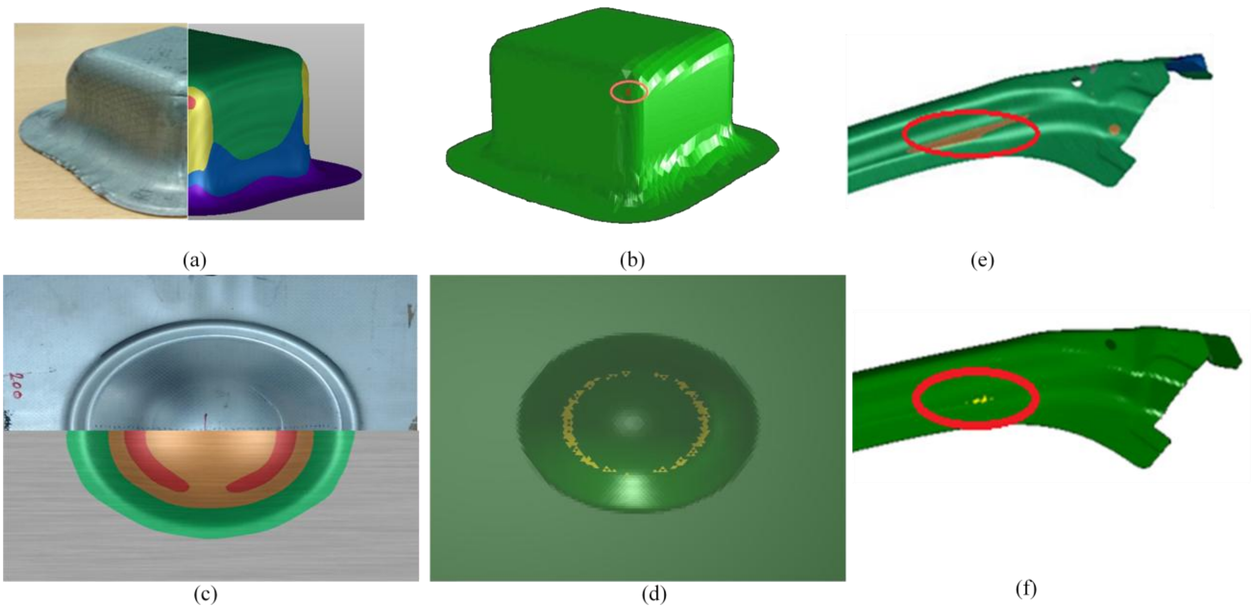

Figure. 1 Square Cup with flange (a) Simulation and experimental results, (b) SNI based failure location, (c) Equibiaxially stretched sheet simulation and experimental results, (d) Equibiaxially stretched sheet SNI based results, (e)Numisheet benchmark-2 Simulation results, (f)Numisheet benchmark-2 SNI based results

Table 1. Material Properties

Sr. No	Material Name	Yield strength (MPa)	Work Hardening Exponent	Anisotropy	Strength Co-efficient (MPa)	Sheet Thickness in (mm)
1	TL1550Z	258.8	0.194	1.24	594.2	1
2	HX260LAD	245.4	0.174	0.94	605.8	1
3	HC180BD	193.1	0.183	1.5	511.76	0.6
4	DC04	183.0	0.204	1.64	518.95	1
5	AA6016	127.4	0.241	0.59	423.69	1.25

Also seen in Figs. 3a-b are the draw depths at which failure was indicated by experiments, FLD and the SNI based criterion for square cup and equibiaxially stretched blank. It may be observed that the prediction of draw depth at failure using the SNI based criterion (circular mark) is close to the experimentally observed draw depth at failure (triangle). A square mark indicates FLD based failure prediction. In equibiaxial stretching (Fig. 3a), AA6016 shares the band with three varieties of steel.

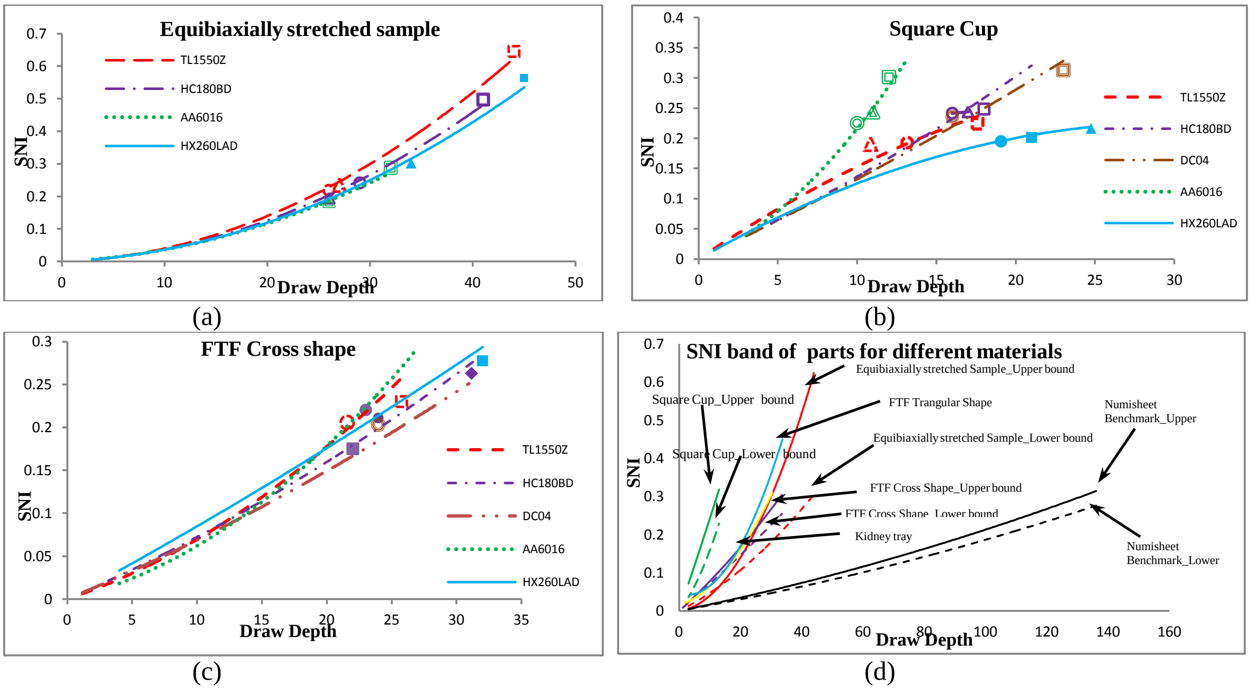

Figure 3: SNI vs. Draw Depth (○ - failed as per critical SNI, △ - Failed, Experimentally, Rectangular mark indicates failed simulation) □

Table 2. Coefficients of trend lines for evolution of SNI with draw depth.

Sr.No	Part Name	Material	a	b	R^2
	Equibiaxially stretched sample[1]	TL1550Z	0.0003	0.001	0.99
a	Equibiaxially stretched sample	HC180BD	0.0003	0.0011	0.99
	Equibiaxially stretched sample	AA6016	0.0002	0.0014	0.99
	Equibiaxially stretched sample	HX260LAD	0.0002	0.0012	0.99
	Square Cup	TL1550Z	0.0002	0.0178	0.97
	Square Cup	HC180BD	0.0001	0.0122	0.96
b	Square Cup	DC04	0.00008	0.0124	0.97
	Square Cup	AA6016	0.0011	0.0102	0.99
	Square Cup	HX260LAD	0.0003	0.015	0.98
	FTF Cross Shape	TL1550Z	0.0002	0.005	0.98
	FTF Cross Shape	HC180BD	0.00008	0.0065	0.97
c	FTF Cross Shape	DC04	0.00006	0.0063	0.96
	FTF Cross Shape	AA6016	0.0003	0.0035	0.98
	FTF Cross Shape	HX260LAD	0.00003	0.0082	0.96
	Equibiaxially stretched sample_Max	All materials	0.0003	0.001	0.99
	Equibiaxially stretched sample_Min	All materials	0.00007	0.004	0.99
	Numisheet Benchmark_Max	All materials	0.000005	0.0016	0.86
	Numisheet Benchmark_Min	All materials	0.000005	0.0014	0.91
d	Square Cup_Max	All materials	0.00008	0.0235	0.82
	Square Cup_Min	All materials	0.0006	0.0101	0.92
	FTF Cross Shape_Max	All materials	0.00006	0.0072	0.97
	FTF Cross Shape_Min	All materials	0.00002	0.0069	0.95
	Kidney Tray	TL1550Z	0.0002	0.0043	0.97
	FTF Trangular Shape	TL1550Z	0.0003	0.0031	0.99

1. Highlighted to indicate results for TL1550Z material

It may be inferred from the table that the band is the narrowest for Numisheet 2016 benchmark-2, and dependence of SNI on the draw depth, almost linear. For equibiaxially stretched blanks, coefficient 'a' (and hence curvature) remains virtually unchanged over the 5 materials, while 'b' (slope at zero punch travel) is significantly different. For the TL1550Z material parameter 'a' shows no sensitivity whatsoever to the product geometry, while the value of 'b' does.

A similar trend of evolution of SNI with draw depth for a wide range of geometries made from a given single material brings out the utility of the method. A critical SNI would be attained faster in one geometry compared to another, explaining the relatively inferior formability of a given shape using a given sheet metal.

5. Conclusions

1] Failure SNI obtained by experiment is usually very close to that obtained analytically. Hence, the critical SNI obtained for the material can be used for failure prediction.
2] At the initial stage, the rate of change of SNI (which depends on the constant 'b'), depends significantly on the product shape and the material. For a given material the rate of change of SNI depends upon part geometry.
3] Geometry with sharp radii have high rate of change of SNI, which results in early failure
4] For a given part geometry, a narrow band of variation of the SNI with draw depth over several materials shows that there is no need for correlating laboratory results (using samples of a different geometry) with shopfloor experience any more. The shopfloor product itself, may be used as a sample, and evolution of SNI with punch travel established.
5] A change in material would lead to a critical SNI being achieved faster or slower depending on the coefficients of the equation.

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