

Experimental Verification of the Strain Non-Uniformity Index (SNI) based Failure Prediction

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Abstract. Formability of the sheet metal depends upon the uniformity of strain distribution, which depends on material properties, tooling and process parameters. Nakazima Test was conducted to study the strain distribution and establish the forming limits of AA 6016. The experimental conditions were simulated using AUTOFORM 5.2 Plus software and the failure predicted using the SNI based methodology. The failure predictions were correlated with the state of the experimentally deformed Nakazima samples, and also with the FLD based forming limits. The failure prediction from the SNI based methodology was found to correlate well with the state of the experimental Nakazima sample.

Keywords: Nakazima Test, AA6016, strain nonuniformity index (SNI), Forming Limit Curve (FLC).

1.Introduction

Inferences from spatial strain distribution over a sheet metal blank can be drawn based on several observations. Schedin and Melander [2] studied strain distributions of sheet metals using different shapes of grid elements. They also correlated the nature of strain distribution with the mechanical properties of the sheet. The concept of a strain envelop was introduced by Karima et.al [3] which refers to strain distribution plotted in the major and minor strain space. This was meant to identify process changes introduced on account of various reasons. Schedin and Melander [4] showed the effect of strain hardening exponent (n) and normal anisotropy (r) on the thickness strain distribution. Date et. al. [5] defined the strain non-uniformity index (SNI) based on strain distributions which result from complex interactions among forming parameters.

Predicting failure based on the SNI involves analysing strain distribution on a large number of critical planes. It is possible that the SNI on many critical planes attain failure at the same time. This enables predicting multiple locations of failure. However, this process is time consuming as large number of strain distributions have to be analysed.

It was therefore thought that the process of detecting onset of failure could be speeded up using the 'Global SNI', or the GSNI, which is one single value determined over the entire blank. 'Global' Strain non-uniformity index (as opposed to that for several critical planes) is simply the peak strain over the



entire blank minus the average strain over the entire blank. It is computed from the strain distribution, (that obtained from a simulation, for instance) over the entire blank.

The objective of this paper is twofold, i.e., to see if a GSNI value could be identified to mark the onset of failure, so that one need not analyse strain distributions on the numerous critical planes in the safe regime of deformation, and to look for a possibility of correlating the GSNI with the critical SNI. To this end, both experiments as well as simulations were performed.

Nakazima test is the most common method for evaluating the forming limits of sheet metal thickness ranging from 0.5 mm to 3.3 mm [1]. The Nakazima test geometry, being relatively simple and standard, was used for this study.

2. Work Plan

Nakazima test was performed on AA 6016 sheet using six blank widths ranging from 75mm to 200mm. Circles of 2mm diameter with centre spacing of 3mm were laser marked on each of the blanks which were stretched to failure over a punch of 100mm diameter. The blank of 75mm width alone remained safe, as it would often tear near the bead. The press capacity was 70 tons and the blank holder force went up to 60 tons. The experimental parameters were noted and used for simulating the set of Nakazima tests using the AUTOFORM 5.2 Plus software. The properties of AA6016 used in the present work are given in Table 1. The major and minor strain distributions along with nodal and elemental data are obtained at every deformation step, and used to predict occurrence of failure based on the FLD as well as to determine the SNI and thereby predict failure.

Table 1. Mechanical properties of material

Material	Density (MPa/mm)	Young's Modulus (GPa)	Poisson's ratio (μ)	Anisotropy Parameters (orthotropic)			Strain hardening exponent (n)
				Plastic Strain Ratio, R			
AA6016	2.7 E-05	70	0.3	0°	45°	90°	0.245
				0.61	0.49	0.7	

As the draw depth progresses, number of elements on the blank increases due to mesh refinement in adaptive meshing. The amount of non-uniformity in the strain distribution is quantified using strain non uniformity index [5]. The value of SNI for the longitudinal meridional strain distribution was obtained experimentally by grid strain analysis and analytically by an FEM simulation.

The GSNI was determined using simulation data only, while the SNI was determined analytically as well as experimentally.

3. Results and Discussion

It was found from experiments that the blanks of all six widths failed close to 30mm of dome height. The height of the dome was measured using a height gauge. Table 2 below shows the SNI, GSNI and the condition of the samples at experimental dome height of 30 mm for all 6 samples. The 'failure' in case of GSNI was determined using the FLD. For instance, for a blank of width 200mm, simulation was performed up to a punch travel of 30mm (the travel at which experimental samples failed), and were found to be 'safe' according to the FLD.

Though in simulation, the dome height could be higher than 30mm in actual experimentation the onset of crack occurred at 30 mm for all blank widths. It may be observed from Table 2 that the GSNI did not show significant variation over the six blank widths. Based on the FLD, four of the blank widths were predicted to be safe. The SNI from experiments differs with that from simulation because the actual experimental conditions cannot be reproduced in a simulation. For instance the prevalent

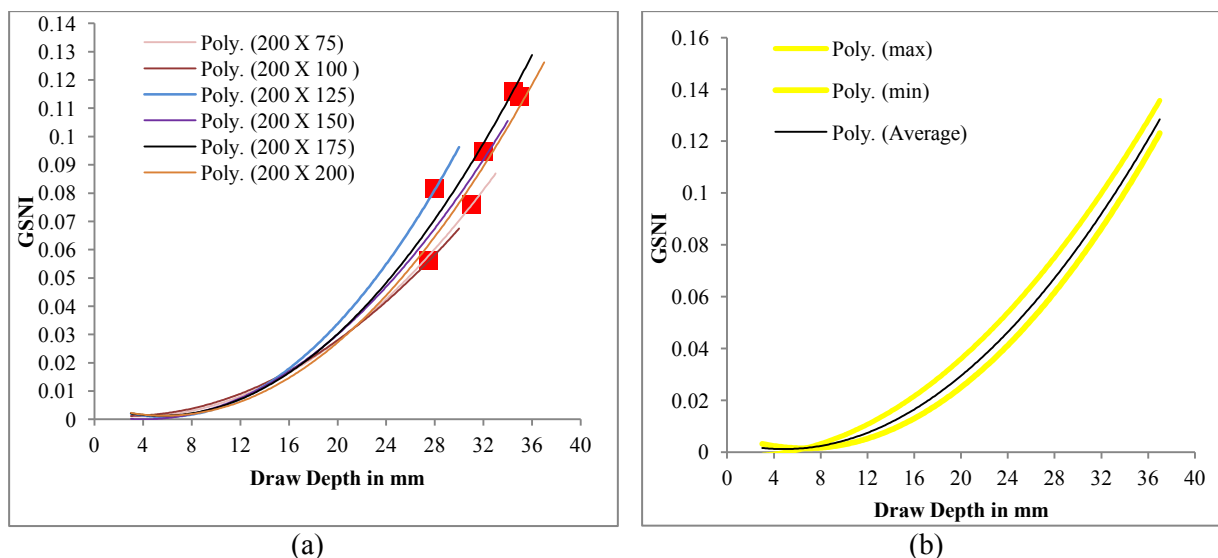
coefficient of friction, the actual holding force, different techniques of obtaining the SNI all contribute to the difference among experimental and analytical values. The condition of the sample as predicted using simulation based SNI seems to correlate reasonably well with the experimental observations, while those using the FLD correlated exactly for two blank widths.

Table 2. SNI values and condition for experimental draw depth

Blank Dimensions	Draw Depth (mm)	Experimentation		Simulation Data, FLD Based Prediction		Simulation based SNI Prediction	
		SNI	Condition	GSNI	Condition	SNI	Condition
200 X 200	30	0.180	Failed	0.073	Safe	0.235	Risk of Split
200 X 175	30	0.210	Failed	0.084	Safe	0.234	Risk of Split
200 X 150	30	0.201	Failed	0.076	Safe	0.252	Risk of Split
200 X 125	29	0.255	Failed	0.088	Failed	0.209	Risk of Split
200 X 100	30	0.223	Failed	0.070	Failed	0.191	Risk of split
200 X 75	30	0.079	Safe	0.070	Safe	0.137	Safe

The variation of GSNI with punch travel (upto failure as per the FLD) shown in Figure 2a shows a narrow band of variation across the six blank widths studied. The red coloured rectangular blocks indicate the GSNI calculated from the simulation data at the onset of necking or cracks. From simulation it the GSNI values were found to increase with the increasing width of sample, due to a greater spatial non-uniformity of strain distribution. The narrow band describing variation over six blank widths may be represented by a single line indicating the average GSNI (Figure 2b). The extreme lines of the band lie within ± 0.02 of the average GSNI.

Figure 2 (c) indicates the correlation of experimental SNI with GSNI and the SNI determined from simulations. The correlation coefficients for the two relations are not very high on account of scatter seen in the figure. However, with respect to the experimental SNI, the simulation based SNI shows a variation of less than 0.05 from the least squares curve representing the fit. The difference in GSNI and simulation based predicted SNI is due to strain peaks being captured along the meridian of the sample, whereas calculation of the GSNI involves the strains over the entire area of the blank.



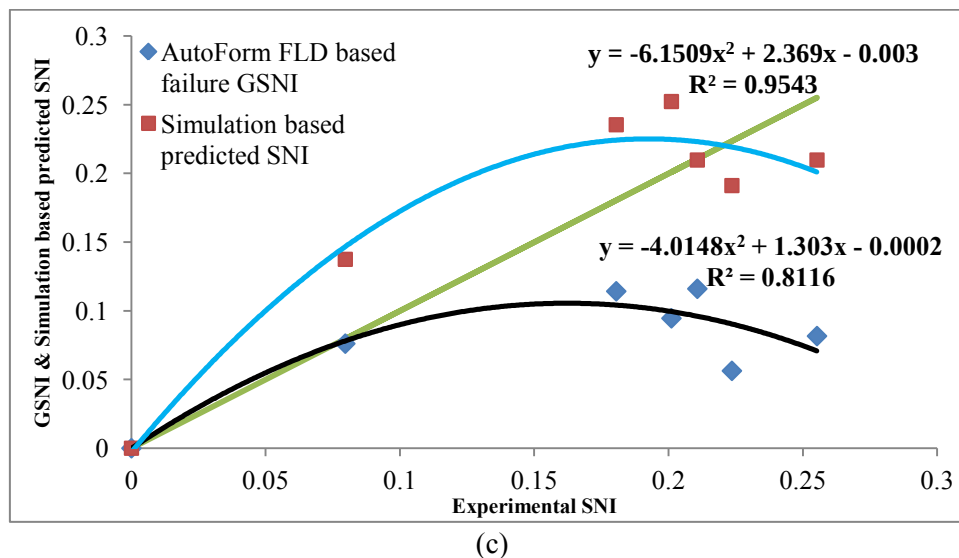


Figure 2. Draw depth vs. simulation based GSNI (a), bandwidth of GSNI along with its average (b) and correlation of experimental SNI with SNI and GSNI (c)

Also, in simulation based SNI prediction the strain values are taken along a multiplicity of critical planes, whereas the longitudinal meridional strain nonuniformity represents the SNI in the experimental Nakazima blank. The values of simulation based predicted SNI and experimental SNI are comparable with each other.

The average value of SNI at failure by experimentation (over the 6 blanks) is about 0.19 and that by simulation based SNI prediction program at failure turns out to be about 0.21, which are fairly close.

4. Conclusions

- 1) The relation between the experimental SNI and the analytically determined SNI and GSNI is nonlinear. The constants of the equation will depend on the material.
- 2) The analytically predicted SNI differs from the experimental SNI due to deviation of actual experimental conditions from those in simulation. Moreover, differences in method of obtaining the strain distribution also contribute to the difference.
- 3) The variation in GSNI with blank width across the 6 blank widths studied lies within a narrow band that is ± 0.02 wide.

5. References

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