

Application of Strain Non-Uniformity Index (SNI) Based Approach to Predict Failure in Sheet Metal Components

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Abstract. Industrial components are far too complex in shape and far too large in size compared to the laboratory scale test samples used to establish failure criteria like the forming limit diagram (FLD). These have been traditionally used to predict failure, but are found to often make wrong predictions due to their sensitivity to strain path, and forming conditions like temperature. The Strain Nonuniformity Index (SNI), a single parameter determined from the spatial strain distribution, may be used to predict failure and identify locations of failure or even imminent failure. This is possible regardless of temperature or even the method of forming (cold forming, hot forming, superplastic forming etc.). The paper presents a few results demonstrating successful applications of this novel SNI based technique.

Keywords: Sheet Forming, SNI; FLD; strain distribution; failure prediction; failure location

1. Introduction

Automobile components made from sheet metal are used as skin panels, crash structures, chassis members, structural members like the A, B and C pillars and reinforcements of a variety of shapes and sizes. This generates a spatial variation of strains over the entire sheet. Often components show either unacceptably large extent of thinning, necking, and even cracking. It is important to know the potential 'failure sites' so that the tools can be designed accordingly. Actually, these failure sites are a combined outcome of the component design, shape (design) of the blank from which it was drawn, followed by tool design and the forming variables like lubrication, blank holding scheme and the press speed.

An apriori assessment about likely failure sites is often made using the forming limit diagram (FLD) so that all anticipated problems could be rectified and die rework thereby avoided. Dies are themselves very expensive, and reworking them adds significantly to the cost. At what point in punch stroke an issue might arise can be indicated using the FLD.

The FLD is however, dynamic (dependent on the material properties and prestrain) and is highly sensitive to strain path. The present work presents examples of the strain distribution based methodology (published earlier [1, 2]) for anticipating failure and identifying the potential locations of failure. This methodology applies with equal facility to different materials and is irrespective of the processing route as one relies on the strain distribution and not how it was produced.



2. Strain distribution based methodology

The quantities, namely, the Strain Non-uniformity Index (SNI) and the Constraint Factor (CF) characterise a strain distribution [1]. The maximum degree of strain non-uniformity is of interest. Hence a plane passing through the points of highest deformation, least deformation and the direction of forming would encompass this greatest non-uniformity in strain. Such a plane is called a critical plane.

In a given component one might have a multiplicity of critical planes and those with the maximum SNI are of interest in order to predict failure. Once the values of SNI in these planes exceed certain threshold value failure is deemed to be imminent / have taken place at the point of peak major strain and maximum thinning.

In the present work, strain distributions from Nakazima test samples at failure were used. Some of the samples were safe as well. A relation correlating the normalised SNI of major strain with the normalised SNI of thickness strain was obtained. Here the SNI for the strain distribution in a given plane was normalised by the peak value of strain in that plane. It was found that the correlations for different blank widths lay onto a single quadratic curve. This way, a common relation could be worked out between the normalised SNI of major strain with that of thickness strain across all blank widths of a given material.

Further, Nakazima tests performed on about 21 materials (sheet metal grade + sheet thickness defines one material) showed that the quadratic curves of several materials lay in a narrow band. Here, among the 21 materials was an aluminium alloy as well. This shows that the set of 21 quadratic curves could be replaced by a single average quadratic curve without any significant loss of accuracy.

In other words, if the quadratic curve to determine the SNI at failure for a given material is available, one uses the equation that is established by experiment. However, for a material that is not among the 21 materials studied, one can still, without introducing significant error, determine the SNI at failure. Hence the quadratic equation for an untested material need not be available for using this methodology. Availability of a quadratic curve would, however, enhance the accuracy of prediction.

Since the curve correlates the normalised SNI of major strain with that of the thickness strain, each critical plane now has an individual SNI at failure. All critical planes therefore would not fail at a single threshold SNI, which was the case in the previous studies presented. This way, the SNI of a critical plane has to exceed the threshold SNI for that plane for that instant. The threshold SNI itself is dynamic (changing with progression) and this enables a more accurate prediction of the location of failure.

The above observations are understandable since the degree of nonuniformity in thickness strain distribution is driven by the degree of nonuniformity in the major strain distribution, with the minor strain influencing the intensity of the thickness strain nonuniformity for a given non uniformity in the major strain. The constraints from the tool and the frictional conditions, together determine the distribution of the minor strains, particularly in view of minor strain being most influenced by the tool contact conditions as documented earlier by Backofen [3]. The development of a minor strain thereby influences the biaxial strain path. This is why the SNI of the thickness strain incorporates the effect of the strain path.

Application of this methodology to the results of strain distribution from AUTOFORM simulations of skin panels of a car is illustrated in Fig 1 (a and b). The locations of failure predicted using the methodology mentioned above is in line with the shop floor experience.

3. Results and discussion

AUTOFORM simulations for components A, B, and C served as a means of obtaining the strain distribution all over the component. The failure strains were represented using the FLD and locations of failure predicted. Alternately, the strain distribution over the component permitted failures to be marked based on the SNI exceeding the failure SNI established experimentally using Nakazima tests.

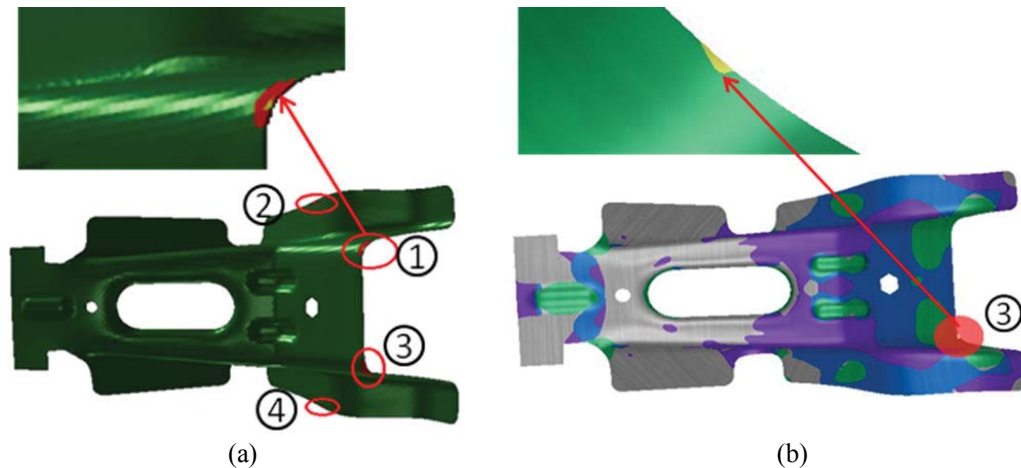


Fig. 1. Failure locations in an industrial component A: (a) Using the SNI based failure criterion (b) Using the FLD. Strain data in both the cases came from AUTOFORM simulations

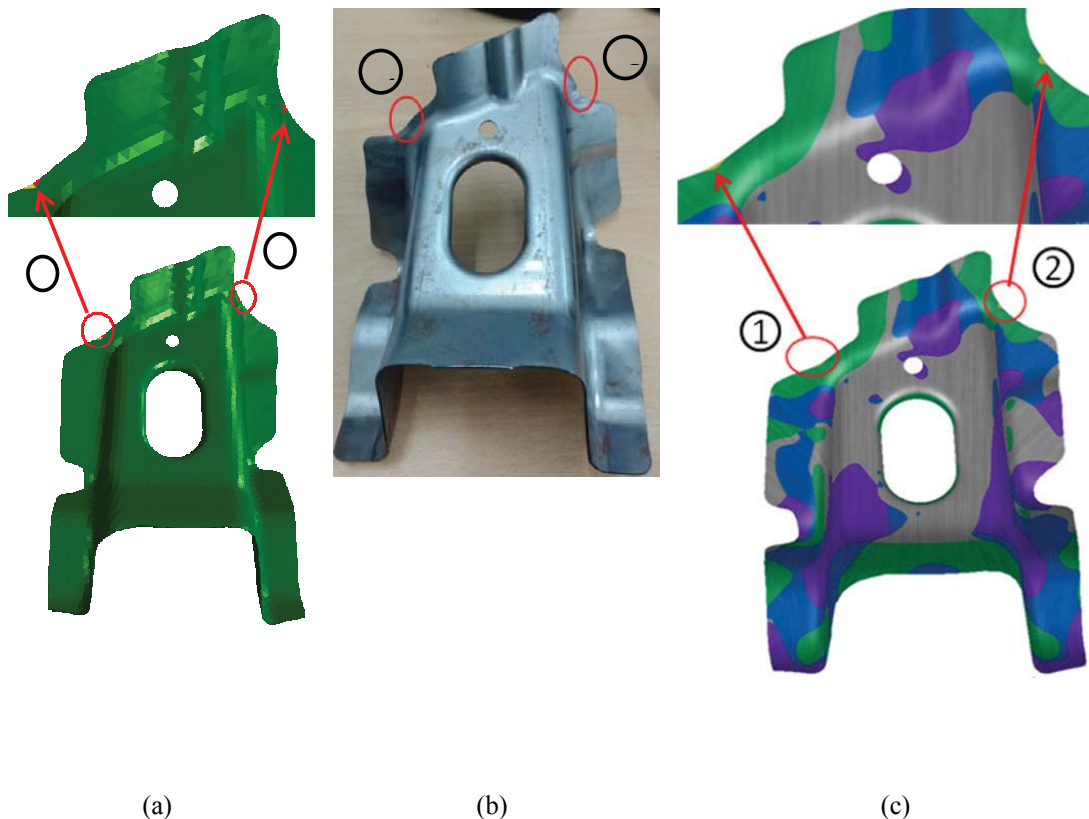


Fig. 2. Failure locations in an industrial component B: (a) Using the SNI based failure criterion (b) On the formed component (c) Using the FLD. Strain data in (a) and (c) came from AUTOFORM simulations

It is not necessary to use Nakazima tests to establish the threshold SNI. The component itself could have been used for the purpose. As seen in Fig. 1 (a) and (b) for component A, the strain distribution based methodology predicts failures at four locations while the FLD based predictions (for the same component simulated using AUTOFORM) shows only one location of failure. For component B, Fig. 2 (b) represents the shop floor experience. The failure locations predicted by both, the SNI as well as the FLD correlate well with the actual failure locations. A similar observation may be made from Fig. 3 pertaining to Component C.

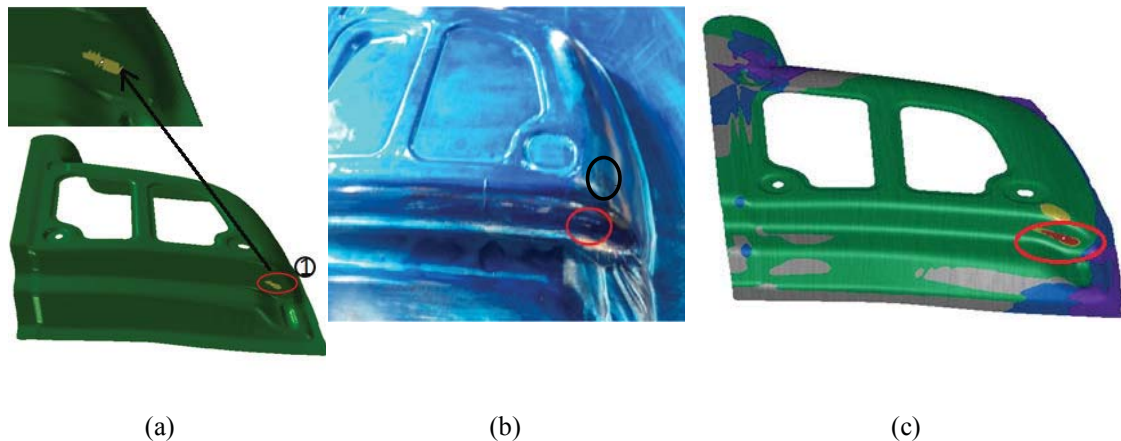


Fig. 3. Failure locations in an industrial component C: (a) Using the SNI based failure criterion (b) On the formed component (c) Using the FLD. Strain data in (a) and (c) came from AUTOFORM simulations

From the foregoing, it appears that predictions using the SNI based methodology seem to be as good as those made using the FLD, faring a little better occasionally.

The observations made confirm that the relatively simple strain distribution based methodology can serve as a viable criterion to predict the occurrence of failure and its location.

4. Conclusions

- 1) The strain distribution based failure criterion, namely the SNI is capable of predicting the occurrence of failure and its location.
- 2) Simplicity of establishing the failure location irrespective of the forming process, strain path, temperature and inconsistent lubrication makes the SNI a viable alternative to predict failures especially at the design stage.

5. References

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