Effect of Pre-Strain on Ductile Fracture in Aluminum Alloy 5052

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Abstract

Metallic components may develop plastic deformation before in-service loading (pre-strain) due to manufacturing process and/or unexpected loading. This pre-strain not only affects the yield strength of the material but also influences its fracture properties. The work presented here employed laser drilled model materials to better understand the effect of pre-strain on ductile fracture in aluminum alloy 5052. The effect of pre-strain on void growth and linkage leading to fracture is studied. A non-local damage is used in a finite element model to predict linkage between voids. The precise arrangement of the laser holes can be exactly reproduced in the finite element model which allows the model to be validated with the experimental results.

Introduction

Pre-Strain Definition:

Some Applications of Pre-strain:

- Pipe Reeling
- Earthquake
- Automotive industry

The Importance of Pre-Strain:

There are many engineering scenarios where metallic components are subject to plastic deformation (pre-strain) before the final use of a part.

It is therefore necessary to understand this process for different materials and then predict the potential risks and failure in industrial settings.

Methodology

Part One: Experimental Procedure
1. Machining of small tensile samples out of a sheet of Al alloy 5052
2. Annealing of tensile samples (T=450 °C for 30 min)
3. Doing the pre-strain tests (5%, 10%, 15%, 20% and 25%)
4. Laser machining to create voids in the samples (Power=0.023 W, microscope objective= 10x)
5. Sample polishing (1 min on 4000 grit paper, then 1 min with OPS)
6. Final tensile test under optical microscope to acquire pictures in-situ
7. Fracture surface analysis in the Scanning Electron Microscope (SEM)

Part Two: Experimental Data Analysis

- The major diameter of the voids (a) was extracted using an image analysis software (Image J)
- The ratios of a/a0, (where a0 is the initial length) were plotted versus the far field true strain and compared with the finite element model
- Fracture surface area was measured from SEM images

Results and Discussion

- Effect of pre-strain on void growth

The graph presented below shows the effect of pre-strain on void growth. The larger the pre-strain, the faster void growth and earlier the failure takes place. This is explained in terms of work hardening rate. By increasing the pre-strain in the sample the work hardening rate decreases which favours void growth.

- The effect of Pre-Strain on ductility

Ductility of a material is expressed quantitatively as a percent reduction in area. The area reduction of the samples was extracted from images of the fracture surface obtained with the SEM for different pre-strains:

SEM images of the area extracted from fracture surfaces (yellow contours)

The change in ductility (true fracture strain) versus amount of pre-strain is shown below. A decrease in strain to fracture is observed with increasing pre-strain.

Conclusions and Future work

- Void growth was investigated for various amounts of pre-strain in the aluminum alloy 5052.
- The ductility of the sample decreases with increasing pre-strain.
- Finite element simulations based on a non-local averaging scheme was able to predict both void growth and failure strains.
- Simulations will be carried out for different pre-strain.
- In this particular case, pre-strain was applied in the same direction as the final straining path. Further experiments will investigate the effect of strain path changes (pre-strain in tension followed by straining to failure in orthogonal direction).
- Digital image correlation will be used to extract local strains between voids and for comparison with finite element simulations.

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