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Development of FLD Diagrams from Strain Analysis Using ImageJ Processing

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Abstract

In this work, one of the major mechanical behaviour of aluminium alloy sheets under certain load is obtained i.e. by forming limit diagram curves FLD. Experimental, analytical, and numerical investigations are carried out to analyse in detail the process. Based on the approaches, properties of the structure deformed into the cup shape with different strains produced are studied. In the sheet forming process, plastic instability may occur, loading to defect products. Thus optimization method functions are used to identify parameters of failure criteria. Finally, a good correlation is obtained between experimental and numerical studies.

Keywords: aluminium alloy, behaviour, failure criterion.

1. Introduction

Forming limit diagrams (FLDs) help designers to predict the success probability of a sheet metal forming process such as automobile body manufacturing. Understanding the forming behaviour of a sheet metal is the key to its practical efficacy, along with a thorough production cost analysis. The FLD has been widely accepted as an effective tool for the formability analysis of sheet metals. An FLD, or forming limit curve (FLC), is often used to predict the forming behaviour of sheet metals. Introduced by Keeler and Goodwin in the1960s, FLDs could be achieved both theoretically and experimentally. To find the FLD, the sheet metal is subjected to various stress combinations leading to various sets of principal stresses and principal strains. Sheet metal formability is generally defined as the ability of metal to deform into desired shape without necking or fracture. Each type of sheet metal can be deformed only to a certain limit that is usually imposed by the onset of localized necking, which eventually leads to the ductile fracture.

A well-known method of describing this limit is the forming limit diagram (FLD), which is a graph of the major strain ($\varepsilon 11$) at the onset of localized necking for all values of the minor strain ($\varepsilon 22$). The diagram can be split into two sides; "left side" and "right side". At the "right side", which was first introduced by Keeler and Backofen only positive Major and Minor Strains are plotted. Goodwin completed the FLD by adding the "left side", with positive Major and negative Minor Strains. Various strain paths can be generated in order to create different combinations of limiting Major and Minor Strains.

Usually FLDs are determined by using one of the following two types of test methods. The first one is the Marciniak in-plane test where a sheet metal sample is strained by a flat-bottomed cylindrical punch. Between the punch and the metal sheet is a steel driver with a hole in the Centre. This creates a frictionless in-plane deformation of the sheet. The other test is the Nakazima (Dome) out-of-plane test, which uses a hemispherical punch. Since for this test deformations are not frictionless, lubricants are used. The necessary strain paths are obtained by using different lubricants, creating different friction conditions, and also with different sample widths. In this work, Nakazima (Dome) out-of-plane test is used. FEA usually gives the information of forming process such as the deformed shape, strain and stress distribution, punching load, and the fracture. Recently, several

Researchers have used ductile fracture criteria to determine the limit strains.

The limit strains were determined by substituting the values of stress and strain histories calculated by the finite element simulations into the ductile fracture criteria. For this purpose, some sheet metal specimens of constant lengths and variable widths are stretched by a hemispherical punch (out-of-plane stretching) or flat punch (in-plane stretching), and some constant geometry specimens are stretched using different lubricants.

In this a study on aluminium behaviour is reported. This alloy contains nominally magnesium and it presents a medium strength, good weldability and good corrosion resistance in marine atmospheres. The metallurgical state of the aluminium alloy used in this work is as received. It has a lower density and an excellent thermal conductivity compared to other aluminium alloys. It is the most commonly used type of aluminium in sheet and platforms.

The behaviour and resistance of aluminium sheet plates is strongly dependent on the material behaviour under dynamic loading. The properties of the structure are intensely related to the material behaviour and to the interaction between the projectile and a thin aluminium target during the perforation process.

Therefore, to find expected curves, many dynamic constitutive relations have been studied in several works. For instance, proposed a dynamic constitutive relation based on a phenomenological approach.

The chemical composition of the aluminum alloy sheet which is used is as follows:

Table 1: Composition of Al Alloy Sheet

Material	%Si	%Fe	%Cu	%Mn	%Mg	%Zn	%Al
Composition	0.127	0.5803	0.0998	0.0039	0.003	0.0112	99

Aluminum Alloys were used in this study. These are widely used to make body panels in automotive industry due to their good stretch- ability. The chemical compositions of the Aluminum Alloys used in this study. Whereas the used aluminum alloy sheet is as follow:

Aluminum 1100-AA (19000 BIS) is soft, low strength and, at 99% aluminum composition, is the commercially pure grade among aluminum alloys. Aluminum 1100 (19000) is a soft material and is used to make many common household items, such as cooking utensils, household foil, and food containers. Aluminum is also used in wide range of industrial applications, involving both thermal and electrical conductivity.

Experiment on UTM

Figure 1: UTM Machine

2. Literature Review

The forming limit diagram (FLD) is a useful concept for characterizing the formability of sheet metal. In this work, the formability, fracture mode and strain distribution during forming of Ti6Al4V titanium alloy and Al6061-T6 aluminum alloy sheets has been investigated experimentally using a special process of hydroforming deep drawing assisted by floating disc. The selected sheet material has been photo-girded for strain measurements. The effects of process parameters on FLD have been evaluated and simulated using ABAQUS/Standard. Hill-swift and NADDRG theoretical forming limit diagram models are used to specify fracture initiation in the finite element model (FEM) and it is shown thatthe Hill-swift model gives a better prediction. The simulated results are in good agreement with the experiment [1].

The experimental results indicate the significant effect of strain rate on forming limits of sheets, this effect is neglected in all theoretical methods of prediction of Forming Limit Diagrams (FLDs). The purpose of this paper is to modify the most renowned theoretical method of determination of FLDs (e.g., *M-K* model) so as to enable it to take into account the effect of strain rate. To achieve this aim, the traditional assumption of preexistence of an initial geometrical inhomogeneity in the sheet has been replaced with the assumption of a preexisting "material" inhomogeneity. It has been shown that using this assumption, the strain rate would not be omitted from equations; thus, it is possible to demonstrate its effect on FLDs. To validate the results, they are compared with some published experimental data. The good agreement between the theoretical and experimental results shows capabilities of the proposed method in predicting the effect of the imposed rate at the boundary (which is physically the effect of the punch speed difference in sheet forming) on FLDs [2] [3].

This paper presents the implementation of forming limit diagrams (FLDs) by the FEM and experimental method for sheet metals, which are vastly used in automobile industry. Several different methods were employed to measure the strains of the deformed sheet metals in experimental method. The uncertainty of each method was determined, and the most efficient and economical way was introduced. Because of complexity and expensiveness of the experimental method, simulating of the deep drawing test to obtain the FLD has also been implemented by FEM. The FEM results show excellent agreement with experimental data in present work. Hence, the FEM can be a suitable and reliable method to obtain a FLD [4].

2.1 Computational Models for FLD's

Just to investigate how the sheets can behave once they are combined with sheets of other materials, a well-reputed drawing test present by Nakajima was recreated but this time the subject or the part that was used is three-dimensional (3D) by making this model in a FE software ABAQUS. The grating coefficient between the clear (plates or the sheets) and punch is selected to be 0.1 m.

The x-heading and y-heading of the clear holder along with the attached punch is restricted and can only move in z-heading along the pivot. The spaces were demonstrated as deformable solids. The model is depicted by the ensuing relations:

$$f(\sigma) = \sqrt{\begin{array}{l} F(\sigma_{22}-\sigma_{33})^2 + G(\sigma_{33}-\sigma_{11})^2 + H(\sigma_{11}-\sigma_{22})^2 \\ + 2L\sigma_{23}^2 + 2M\sigma_{31}^2 + 2N\sigma_{12}^2 \end{array}}$$

2.2 Experimental Procedure

Materials

This presents the material used i.e. aluminium alloy sheet of three different thicknesses 1mm, 1.5mm and 2mm and the experimentation procedure done by using UTM machine. It presents the mechanical properties of the aluminium alloy sheet by the Marciniak in-plane test where a sheet metal sample is strained by a flat-bottomed

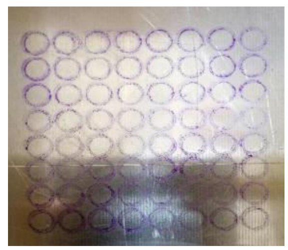
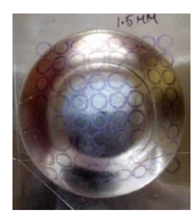


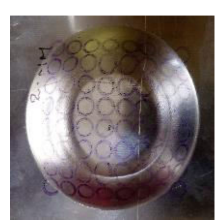
figure1

figure2

Cylindrical punch with punch corner radius as shown below.

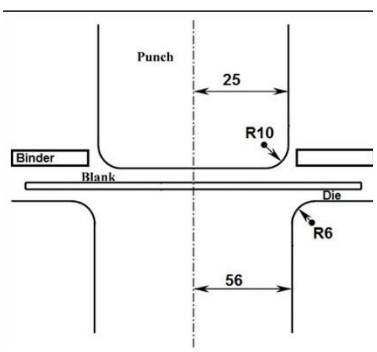
Figure5





The material used in this investigation was Aluminum alloy 1100, the chemical composition of it is given in above **Table 1**.

All specimens with different thickness i.e., 1mm, 1.5mm, and 2mm were gridded with 2.2 mm diameter circles that the distances between their centers were maintained **5.4 mm.** The grids were marked on the specimen by a rubber stamp. In the **Figure 1** the specimen with marked grids of Aluminum alloy 1100 is showed.



The UTM machine that was used in this investigation was an automatic hydraulic press (**Figure 2**). This machine has a maximum load capacity of 40kN, a punching stroke of 250mm and a variable punch speed up to 200 mm/min.

The sheets were clamped between two dies where the die diameter of 56mm and die corner radius 6mm (**Figure3**) made of mild steel and then stretched over a 50mm punch diameter flat with punch corner radius 10mm. (**Figure4**) until they fractured. The grid circles were deformed to elliptic shapes because of stretching strain that was inserted in the plane of the sheet metal during the test.

For each specimen, the major and minor limited strains were measured from the major and minor axes of the ellipse that was located at the nearest distance to the necking zone. The localized necking zone appears as a groove in the deformed region of the sheet metal.

In the **Figure 5** stretched and deformed specimens of Aluminum alloy 1100 have been showed

ImageJ is used to measure the major and minor strains in the deformed circles. The values of the surface strains at the onset of localized necking constitute the FLDs.

ImageJ

ImageJ is A java-based image processing program developed at the national institutes of health and the laboratory for optical and computational instrumentation (LOCI, university of wisconsin).

Its first version, imagej 1.X, is developed in the public domain, while imagej2 and the related projects scijava, imglib2 and SCIFIO are licensed with a permissive BSD-2 license.

ImageJ can display, edit, analyze, process, save, and print 8-bit color and gray scale, 16-bit integer, and 32-bit floating point images.

It can read many image formats, including TIFF, PNG, GIF, JPEG, BMP, DICOM, and FITS, as well as raw formats. ImageJ supports image *stacks*, a series of images that share a single window, and it is multithreaded, so time-consuming operations can be performed in parallel on multi-CPU hardware.

ImageJ can calculate area and pixel value statistics of user-defined selections and intensity-thresholder objects.

It can measure distances and angles. It can create density histograms and line profile plots. It supports standard image processing functions such as logical and arithmetical operations between images, contrast manipulation, convolution, Fourier analysis, sharpening, smoothing,edge detection, and median filtering. It does geometric transformations such as scaling, rotation, and flips. The program supports any number of images simultaneously, limited only by available memory.

IMAGE J software helps in finding the strains in the deformed plates

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The following are steps involved in measuring value of strains using Imagej processing software

Step1: From the menu bar click on "File" and open image which is to be measured.

Step2: Then by taking line command select radius standard circle on the sheet from the girded circles.

Step3: Standard pixel size to be taken in to account by taking standard measurement by click on "Analyze" and then click on "set scale".

Step4: Now by using line command measure the different circles on the sheet which is deformed and press "CntrlM" for the measurement.

Step5: Thus by taking horizontal radius of circle we get minor axis values and by taking vertical radius of circle we get major axis values.

Step6: Then by click on save button results are saved automatically in a excel format.

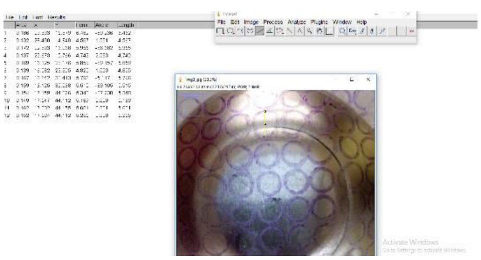


Figure 2: Calculation of Major axis and Minor axis strain values using imageJ

3. Methodology

3.1 Material Selection

Aluminium

The world's richest metal is the Aluminum and this metal contains the worlds outside layer (8%).

Properties of Aluminium

• It is lightweight — 1/3 weight of steel and cooper

• Excellent corrosion characteristics

• Good reflector of warmth and light

• Easy to weld

• Strength to weight ratio of Aluminium is high.

• High thermal conductivity

4. Introduction to CATIA

CATIA is an abbreviation for PC Helped Three-dimensional Intelligent Application. It's one of the main 3D programming utilized by associations in different ventures beginning from aviation, vehicle to customer items.

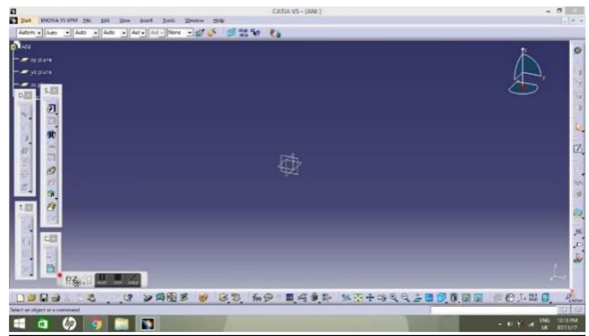


Figure 3 an interface of CATIA

CATIA is regularly utilized at various phases of the arranging - ideate, draw, test, and repeat. The product accompanies various workbenches ("modules") that permit CATIA to be utilized across differed ventures – from parts configuration, surface structure, and get together to sheet plan. CATIA additionally can be utilized for CNC.

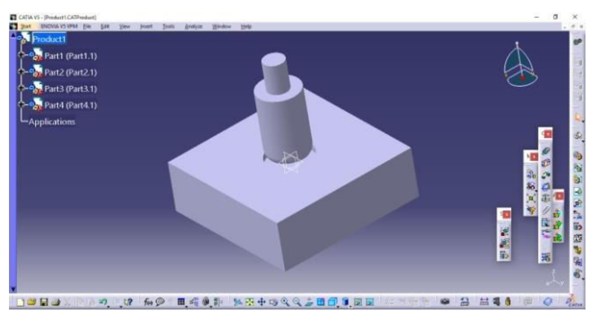


Figure 4: Design of PUNCH in CATIA

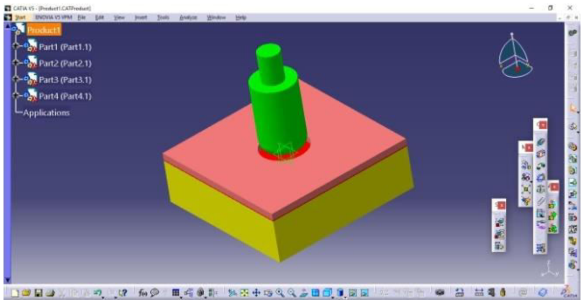


Figure 5: Design of PUNCH with sheets in CATIA

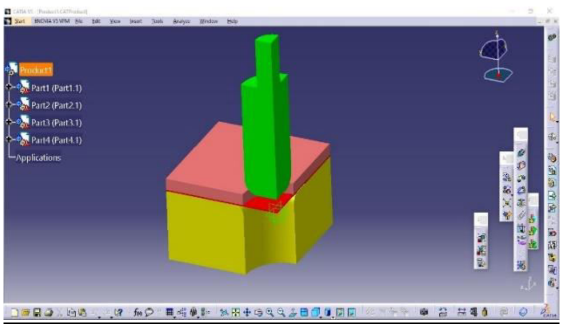


Figure 6: Sectional View of the Punch model

5. Introduction to the Finite Element Method

The fundamental thought inside the limited Component Strategy is to search out the response to muddled issues in a moderately simple manner.

With the advances in innovation and computer-aided design frameworks, complex issues are frequently demonstrated without any difficulty. A few substitute arrangements are regularly given a shot on a PC before the essential model is made. The basics in the designing field are a must to glorify the given structure for the predetermined conduct. Inside the Limited Component Technique, the appropriate response area is considered the same number of little, interconnected sub-districts called Limited components.

Regularly it's difficult to decide the conduct of complex ceaseless frameworks without approximations. For simple individuals like uniform shafts, plates, and so forth. Old style arrangements are regularly looked for by shaping differential and/or basic conditions through the structure like machine outlines, pressure vessels, car bodies, ships, airplane structures, arches, and so forth., need some rough treatment to arrive at their conduct, be it static misshaping, dynamic properties or warmth leading property. Undoubtedly, these are proceeding with frameworks with their mass and versatility being ceaselessly dispersed.

5.1 Need for Finite Element Method

To foresee the lead of structure the maker gets three mechanical assemblies like an orderly, test, and numerical techniques. The methodical procedure is used for the standard regions of known geometric components or locals where the fragmented geometry is imparted numerically.

The course of action procured through the logical method is exact and takes less time. This technique can't be used for inconsistent regions and shapes that need very intricate logical conditions. On the opposite hand, the sensible methodology is used for finding the dark limits of interest. However, the experimentation requires testing gear and a model for each lead of the test. This dynamically requires a high basic theory to pick up the equipment and to make the models.

The arrangement acquired is careful when expended to search out the outcomes and through the readiness of examples too. There are numerous numerical plans like limited distinction techniques, limited component strategy, limit component, and volume technique, limited strip, and volume technique, and limit fundamental strategies, and so on.

Lately, auxiliary streamlining has been joined with the limited component investigation to work out segment checks which will limit weight subject to a few requirements. Such devices are getting valuable and there are numerous examples of generous weight decrease utilizing these strategies.

The arrangement would then have the option to resize fragments to cut back weight or thwart frustration. Fitting sentiments of tension, an unpredictable issue is particularly monotonous structures are resolved using versatile PC cross-section systems to unravel for point by point inside weights. Current constrained part models of plane fragment the goals of low down arrangement are corresponding back or take out weight obsessions remaining weight stressing utilization, hid vague breaks, or single disillusionment causing part dissatisfaction. Weights and as such the constrained segment program envision shirking's, stress, strains, and regardless, catching of the various parts. The organized can then resized sections to scale back weight or thwart dissatisfaction.

5.2 Finite Element Method Process

The Finite Element Examination understands the numerical model, which portrays the physical issues. It's important to evaluate the appropriate response precision. On the off chance that the precision measures aren't met, the numerical arrangement must be rehashed with refined arrangement boundaries until enough exactness is reached.

The rough determination of scientific models will impact the exactness of the appropriate response. The scientific model is settled and checked for the precision then refinement is framed whenever required. Contingent on the degree of exactness, the advancement of segment or shape is performed by connecting the enhancement strategies with the Finite Element Method.

7. RESULTS:

7.1 CAD Model of PUNCH in CATIA:

This chapter presents the mechanical properties like stress, deformation and various strains of aluminum alloy sheets both experimentally and numerically.

7.2 Forming Limit Diagram (FLD) curves

Forming limit diagrams (FLDs) are graphical representations of the limits to forming i.e., the major and minor stresses where local necking occurs. Although cracks are the ultimate limit in forming operations, local necking is usually considered undesirable.

FLDs can be generated by mapping the failure criteria on a graph of two axes representing major and minor strains. The major and minor strains can be measured using sheets with a grid. General techniques available for the grid involve regular patterns of circles, lines or dots, or randomly applied patterns. On straining the grid deforms. The major strain is defined as the strain in the direction of the maximum strain.

The minor strain is the strain perpendicular to the major strain. The major strain is always positive and plotted on the vertical axis, while the minor strain is plotted along the horizontal axis. It can be positive or negative.

The experiment is done on UTM Machine of 400KN Capacity. The following are the values for three different thickness of aluminum alloy sheets

The below are the results during experimentation:

Thickness of Al Alloy Sheet	Cross Head Travel	Area of sheet	Load At Peak	Fracture Strength
1 mm thickness	4.021mm	157.07mm2	11.960KN	76.178N/mm2
1.5mm thickness	5.920mm	235.61mm2	18.960KN	80.47N/mm2
2mm thickness	10.840mm	314.15mm2	24.440KN	77.79N/mm2

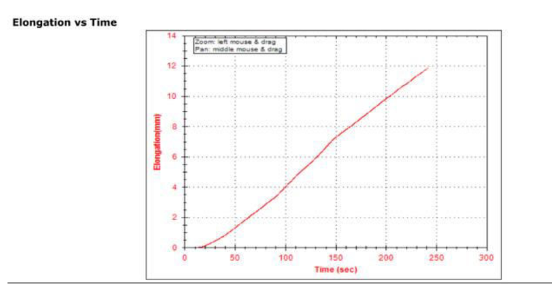


Figure 7: Elongation Vs Time for 1mm Thickness plate

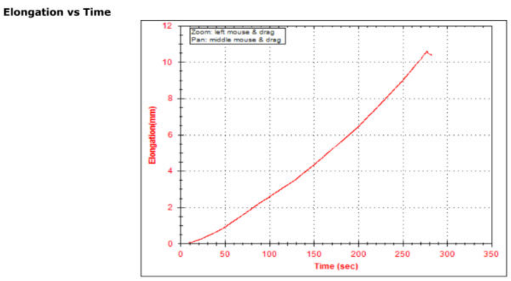


Figure 8: Elongation Vs Time For 1.5mm Thickness Plate

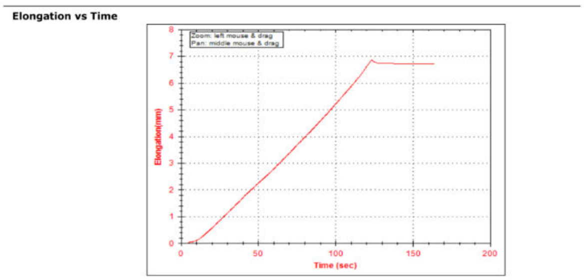


Figure 9: Elongation Vs Time For 2mm Thickness Plate

7.3 Analysis of Aluminium Alloy Plate

The thickness of 1mm:

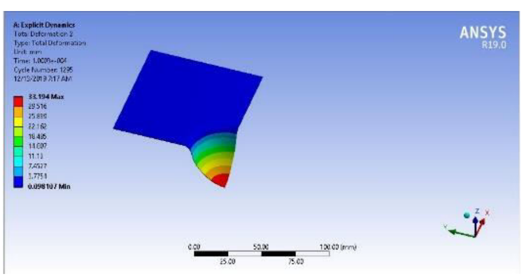


Figure 10: Deformation of a plate of thickness -1mm

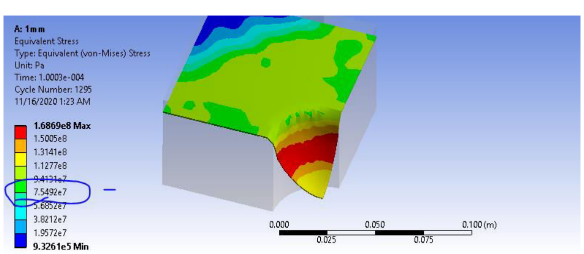


Figure 11 Equivalent Strain of plate of thickness -1mm

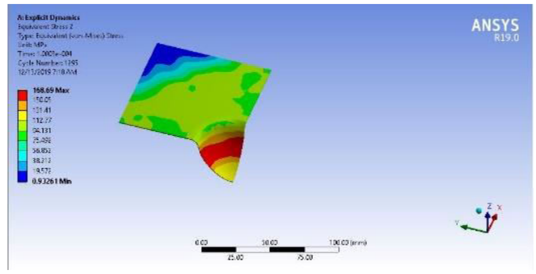


Figure 12 Von-Misses stress of plate of thickness -1mm

The thickness of 1.5 mm:

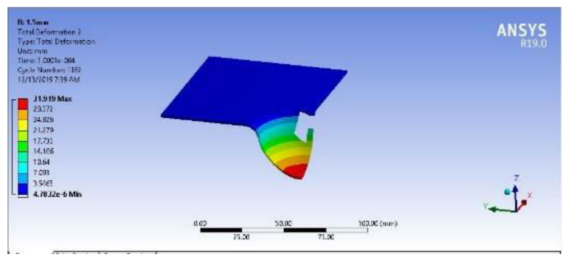


Figure 13 Deformation of a plate of thickness -1.5mm

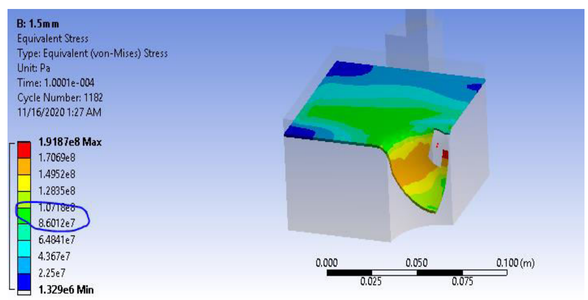


Figure 14 Equivalent Strain of plate of thickness -1.5mm

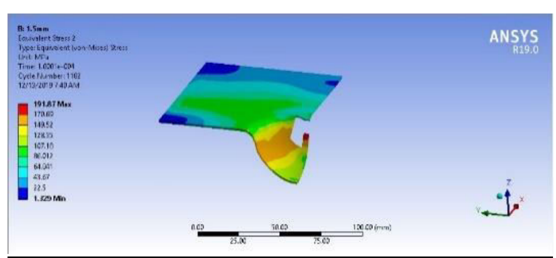


Figure 15 Von-Misses stress of plate of thickness -1.5mm

The thickness of 2 mm:

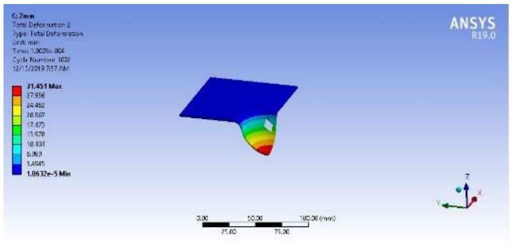


Figure 16 Deformation of a plate of thickness -2mm

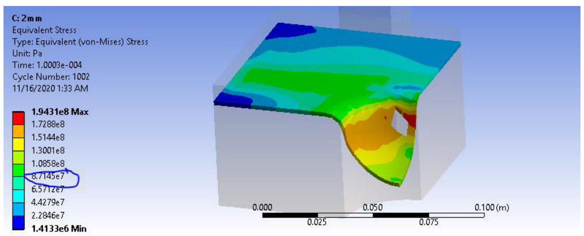


Figure 17 Equivalent Strain of plate of thickness -2mm

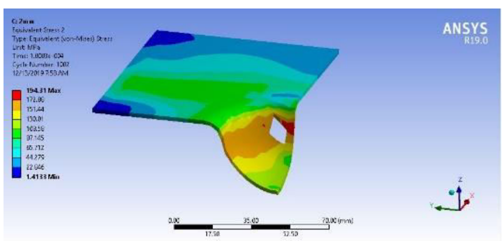


Figure 18 Von-Misses stress of plate of thickness -2mm

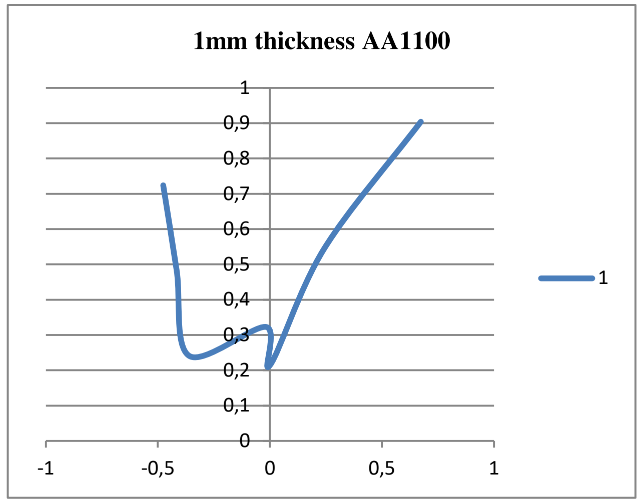
7.4 FLD Curves of Al Alloy Plate:

The thickness of 1mm:

1 mm Thickness Sheet Results

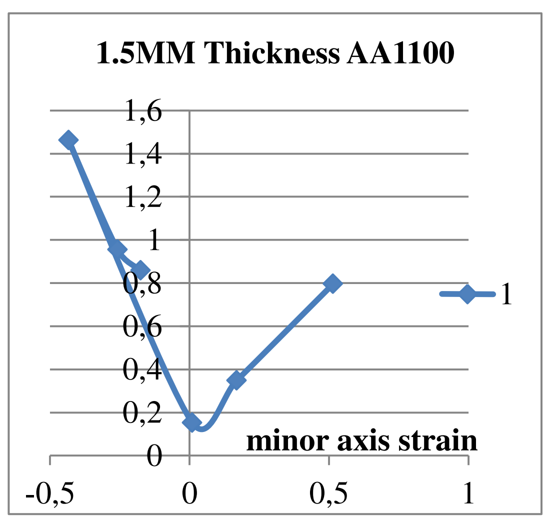
Major axis strain	Minor axis strain
0.904	0.674
0.543	0.241
0.215	0.001
0.323	-0.018
0.241	-0.36
0.483	-0.416
0.724	-0.476

Figure 19 FLD Curve 1mm thickness of pate



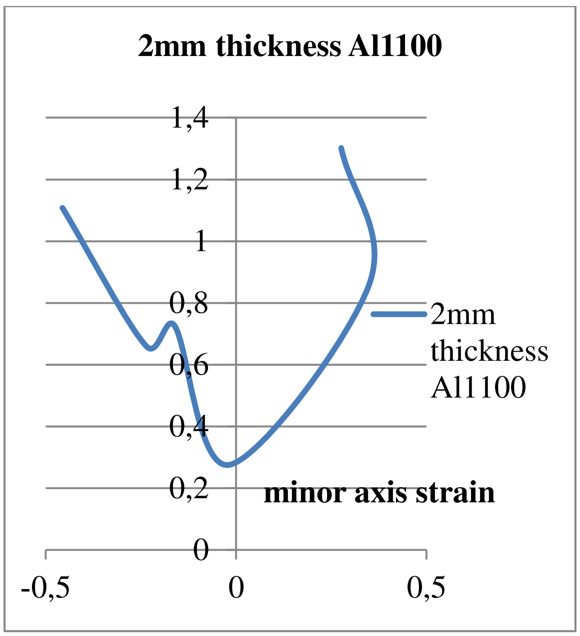
The thickness of 1.5mm:

Major axis strain	Minor axis strain
0.515	0.796
0.169	0.348
0.01	0.153
-0.433	1.462
-0.258	0.955
-0.175	0.859



The thickness of 2mm:

Major axis strain	Minor axis strain
1.302	0.276
0.862	0.35
0.276	-0.017
0.727	-0.162
0.659	-0.235
1.108	-0.456



8. Conclusion and Future Scope

In the present study FLD curves obtained using experimentation and simulation. These curves helps us to pretend the material mechanical properties and help us to predict the material before it comes in to practical approaches. FLD curves mainly used for sheet metal operations. Here we used aluminium alloy sheets of different thickness and we get different type of curves this shows that material properties depend on the thickness too. FLD Curves experiment has the main advantage of knowing the strength and material failure with accurate results. Materials used in Air crafting can also be tested with FLD curves experiment for knowing the exact strains in the materials. FLD curves experiment leads to great innovations in human technology and bring out many new derivations in judging the materials.

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