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Research Article

GTN Damage Modelling of the AA6063 Using Image Processing

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Abstract

In this paper, an innovative way of calculating the Gurson–Tvergaard–Needleman parameter has been developed for AA 6063. AA 6063 is an aluminum alloy comprising the alloying ingredients magnesium and silicon. The Aluminum Association maintains the standard that governs its composition. It has strong mechanical properties and may be heat treated and welded. Image processing technique has been used to calculate the damage constant for the AA 6063. The image of the sample has been taken under a microscope of undeformed and fractured material. Then the images are analyzed using the Open CV tool in a python open-source environment. The initial and final void fraction of the sheet has been calculated. Damage models, particularly the Gurson–Tvergaard–Needleman (GTN) model, are widely used in numerical simulation of material deformations. Each damage model has some constants which must be identified for each material. The direct identification methods are costly and time-consuming. A combination of experimental, numerical simulation and optimization have been used to determine the constants in the current work. Numerical simulation of the dynamic test was performed utilizing the constants obtained from quasi-static experiments. The results showed a high precision in predicting the specimen's profile in the dynamic testing.

1.Introduction

As engineers, we should be aware of the component's life and capabilities before designing it. Damage to glass, pencil lead, window glass, and other failures that do not result in a significant loss, but several failures such as armour penetration, flight components, and other failures can result in a substantial loss. The unadvertised effect of material damage might result in a loss of economic and human life. The failure occurs as a result of faults in the material. This fault might appear as voids, fissures, or strains, among other things. The cause of failure should be investigated further to successfully determine the material's particular working parameters' life and death. A great deal of work has gone into analyzing fractures using a linear elastic fracture mechanics technique. This theory was further developed elastic-plastic fracture mechanic approach. In 1958 Kachnov proposed a damage model which was extended to brittle, plastic, and visco-plastic material. The model has evolved to continuum damage mechanic (CDM) Global and local approaches to fracture The last century, a lot of work has been done to model degradation of strength carrying capacity of structure-carrying capacity of structures for various load types. Griffith(1921) gave an idea of surface energy required to create a new surface. Many such methods evolved, and of the model the fracture This technique has divided the approaches into Global approach and local approach to fracture. Global system It has been found that the fracture mechanics approach proved to be an early tool to model existing cracks. The J-integral is helpful in designing industrial problems. Other approaches like crack tip opening displacement (CTOD) and the crack tip opening angle (CTOA) were proposed. CTOD is time-consuming and difficult to compute as compared to J-integral in finite element computations. As a result of the global approach's limitations, a new local approach to failure has emerged, primarily centred on continuum mechanics.

This approach is based on physical phenomena that take in the material during failure. This approach of damage can be represented the bulk property of material using the CMD model. It is used to model cohesive zone surfaces. It incorporates the effect of discontinuities (microvoids, micro-cracks) modelled within the continuum mechanic framework. Limitation of local and global approach(a) In the type of failure model, minimal no voids are modelled, hence suitable for modelling macro voids and cracks only. (b) It is applied to the initially cracked specimen. Parameter like J-integral is not an intrinsic material property as it depends on the geometry of materials (c). It can be applied to only to simple geometry (d) Alternate approach like CTOD and CTOA have similar problems(e) Advance approach like x-FEM are still mainly used for two-dimension cases for elastic or small plastic deformation. Ductile FractureIn this type of damage model, the material undergoes a large amount of plastic deformation before actual failure of the material. It is characterized by a' dimpled' surface fracture surface. The ductile material consumes a large amount of energy before failure, the rigid material. Ductile damage there are some pre-existing void of void nucleate during with progress of deformation. The voids nucleate, followed by void growth, lead to coalescence with neighbouring voids and materially fail.

Void Nucleation in material voids, nucleation starts by the cohesion of the inclusion from the matrix material or by damage of the inclusion particles. Even if the material is perfect of the same material, void nucleation will not happen evenly. In such type of material, it is the dependent size of particle size. Then nucleation will start with a larger size of inclusion. Void GrowthVoid nucleation is fallowed by void growth. Void growth happens due to the plastic deformation of the matrix material. It is affected by the high triaxial tension—stress-free surfaces of void cause localized stress and strain localization in the adjacent plastic field. As plastic deformation increase, void growth will increase and it shape change. This leads to high deformation. For simplicity, it is assumed that the void does no

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interact in the void growth phase. The formed void is far that their interaction with other crack is not possible or significantly less. There are many expressions that relate to the size of void size with another parameter such as strain, stress, or both. This type of continuum-based model fails to predict failure as this growth rate is not uniform. It overestimates the material as it does not incorporate the effect of the void-void interaction. In actuality, there is softening of the material and materially fails much earlier as predicted by the void growth method. This problem was resolved by Gurson(1977). It utilized an upper bound approach for the spherical rigid void to expect growth in perfectly plastic material. They evaluated the damage by using the f(void fraction) parameter as porosity. The effect of the void was taken into account in the definition of plastic yielding of material.

Void Coalescence is the final stage of failure. At this stage, the cracks have become quite big enough to affect another void in the continuum. The void starts to join this accelerates the process of void fraction tool and die to make products like convention forming. In this step, a tool path is created to give the sheet shape. This procedure is beneficial since it encounters the material's plastic deformation and non-linearity. To deform any material, we must provide a load more significant than its yielding load. Sometimes, due to material inhomogeneity or excessive deformation, the sheet may get fractured, which is again a drawback of the SPIF process. There are many fracture criteria to predict the fracture of sheet material during deformation like Ductile Damage, Johnson-Cook, GTN, etc. Many researchers have conducted many experimental and computational studies in order to anticipate and validate the failure criteria of various sheet materials. Ziaul Haque has presented a new methodology to anticipate necking and failure in ISF using stress-based forming and fracture limit, and its dependability has been proven through experimental and finite element modeling. It shows the predicted failure model is consistent with the empirical observation. Madeira et al. have investigated the limiting strain pairs at fracture in parts showing and not showing the signs of necking before cracking and demonstrating the failure by fracture occur by the tension in crack opening mode-I. They showed that the fracture strain pairs of truncated conical parts, fracture forming limit lines (FFLs) were determined from conventional sheet formability tests, and fracture toughness in crack opening mode. It can be merged to create a new understanding of plastic flow and failure by fracture above the on-set of necking.

2. GTN Model

ABAQUS/Standard and ABAQUS/Explicit can interface with FORTRON to define the material if the proposed model is not available in the Abaqus. This allows us to develop a constitutive new model for the material with the user-defined constitutive relationship. - In ABAQUS/Standard, the user-defined material model is implemented in user subroutine UMAT. In ABAQUS/Explicit, the user-defined material model is implemented in user subroutine VUMAT. Development of the user subroutine has been done on the FORTRAN language. To calculate the void fraction, we needed to define the material model. Material property is defined in providing the yield stress-strain data from tensile test data. So when the load is applied, then there are two conditions either the material can go elastic deformation or it can have plastic deformation. It is found that the void is influenced by the plastic yielding that leads to the growth of the void. The GTNfunction is checked for the yielding condition for each iteration. Strain softening model It is evident from the Gurson yield function that the yield surface squeezes with the growth of voids. Therefore, there is a competition between the expansion of yield surface due to strain hardening and contraction due to void growth. At a significant void volume fraction, squeezing of the yield surface dominates, indicating the loss of load bearing capacity of the material point.The phenomenon is termed here as strain softening. Therefore Gurson model evolves itself the crack growth criteria by loosing the loadbearing capacity of the element.It is thus inherent within the yield function. No external criterion for crack growth is required. The yield function / can be written as

$$p = HydrostaticStress, \sigma_y = FlowStress$$

$$f^* = Void\ Fractionparameter\ df = df_{growth} +$$

$$df_{growth} = (1-f)d\varepsilon_{ii}^{p}$$

$$q_1, q_2, q_3, f_c, f_N, A, S_N, \varepsilon_N\ are\ constant\ \varepsilon_{ii} = I$$

$$\varepsilon_m^p = Effective\ plastic\ strain\ df_{nucliation} = A$$

$$A = \{\ f_N S_N \sqrt{2\pi} e^{-0.5(\frac{d\varepsilon_m^p - \varepsilon_N}{S_N})},$$

2.1 Simulation of the tube

Simulation of ductile fracture was used to validate the GTN model, and the results were compared to the literature [1]. The material property must be defined so that the first value is the Poisson ratio, which is followed by the elastic modulus, and then the data for generating the appropriate strain must be calculated starting from zero strain values. It is necessary to save STATEVAR in order to observe the void fraction output. Anything you want to store and see in the output should go into STATEVAR. In Depvar, the number of a variable used in the STATEVAR should be mentioned. In present work 15, STATEVAR is used to store plastic strain and von Mises.The sehamatic representation of UMAT is given in Fig(1)It represent yhe flow digram of the UMAT coading.

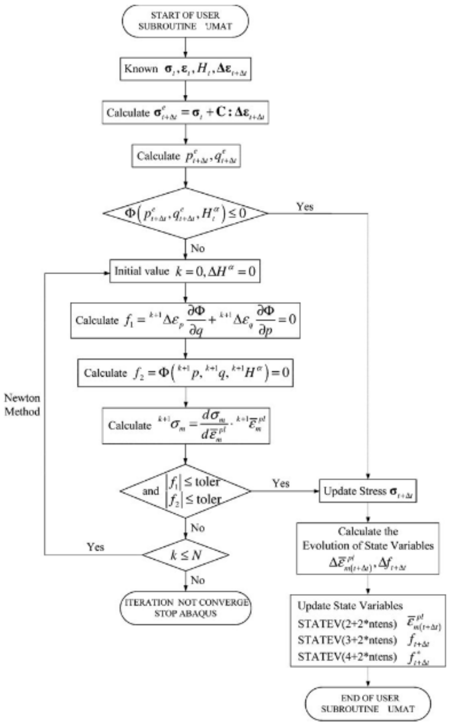
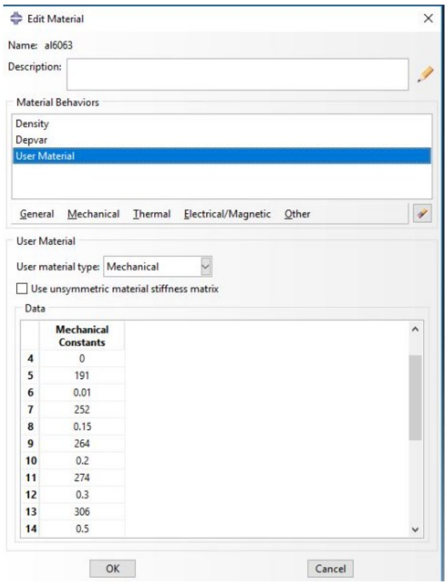


Figure 1. Flow Chart of the UMAT.

$$\phi = \left(\frac{\sigma_q}{\sigma_y}\right)^2 + 2f^* q_1 \cosh\left(-\frac{3pq_2}{2\sigma_y}\right) - (f^{*2} q_3 + 1)$$

$$\phi = GTNFunction, \sigma_q = VonMisesStress$$



Name: al6063

Description:

Density
Depvar
User Material

User material type: Mechanical

☐ Use unsymmetric material stiffness matrix

	Mechanical Constants
4	0
5	191
6	0.01
7	252
8	0.15
9	264
10	0.2
11	274
12	0.3
13	306
14	0.5

Figure 2. Material Property in Abaqus.

In the fig2 represent the material definition in Abaqus. The material is defined by using User Material and yield stress and yield strain is defined.

3. Simulation Result

In this simulation, the values of the strain void fraction are calculated.It is found that void growth is following the same void growth. Void growth is found to be stable up.8 as shown in fig3. Stain and then void growth shoot and material finally fail. The fracture of the void fraction is calculated from the experiment, which is further used as failure criteria of the sheet metal in the deformation process.

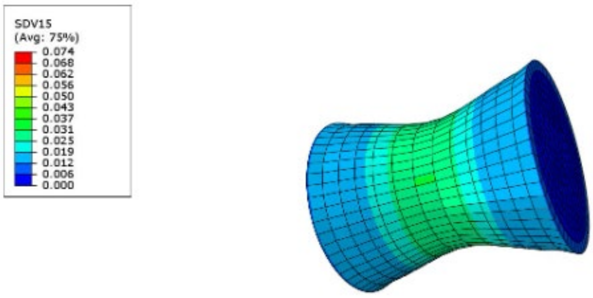
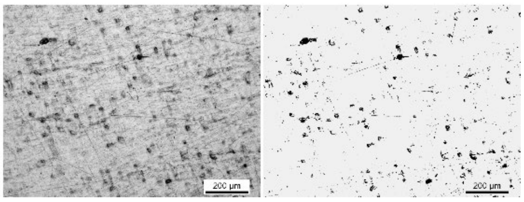


Figure 3. Void fraction in tube in abaqus.

4. Validation of GTN result Validation of GTN result

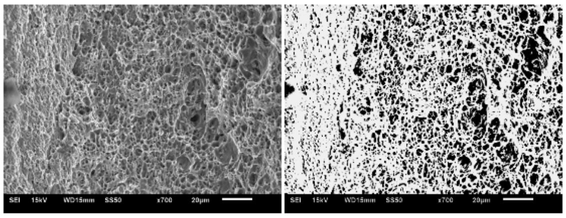
For the validation of the model, a sample of the AA6061 is taken and processed for the observation of the void fraction. The sample is polished using emery paper of grit size 800-2000 respectively and then further fine polished using a rotary polishing machine using a diamond paste of 1 micron. Then the prepared surface is observed under an optical microscope Fig 4. A set of images of the sample were taken, keeping all the parameters the same such as magnification, light intensity, etc. This is done to take care of consistency. Then the greyscale image is processed to calculate the void fraction in the sample. The grayscale image is converted into a binary image by using the intensity void corner.Then the pixel for void and parent material is measured. The value of the void fraction is calculated by manipulating the result of the pixel count of the void and parent material. For image processing python Language is used. CV2 package is used to process the image and calculate void fraction. This image is used to calculate the area of the parent material and voids. The value of the void percentage is around 4 percent. Then the tensile specimens are cut for the tensile test. Tensile testing is performed at the strain rate of 1mm/min.



(a) Gray Image from optical microscope (b) Binary Processed Image

Figure 4. Image of the sheet before damage.

The fracture surfaced is observed under the Scanning Electron Microscope(SEM). The image of the SEM is then processed in a similar fashion to get the values of the void fraction at the fracture surface. The value of the fractured specimen is 40 percent Fig 5.



(a) Grey Image from SEM (b) Binary Processed Image

Figure 5. Image of sheet after damage(fracture).

This void fraction is used as the fracture criteria to predict the failure in the sheet. A few other aspects for void fraction of the material can be calculated with Artificial Intelligence-based approach. With advancements in Artificial Intelligence Techniques, the machine learning algorithms can be exploited in several applications. Various ML approach for different applications have been extensively used in [4-12]. In addition, incremental forming can be employed in development of bio implants [13].

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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