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論　文　内　容　要　旨

報告番号	甲　先　第　**163**　号	氏　名	郭　俊　行
学位論文題目	An experimental and numerical investigation on damage evolution and ductile fracture mechanism of aluminum alloy アルミニウム合金の損傷評価及び延性破壊機構に関する実験及び数値的研究		

内容要旨

The aluminum alloy has been used widely during the past decade in many fields for media strength and good formability. During manufacturing and applying, a variety of problems may be caused by fracture, so its ductile fracture mechanism is still a hot spot. The fracture can not be totally explained by the classic damage constitutive models, reflecting that the damage evolution and ductile fracture mechanism of metal under complex loading is insufficient. The damage evolution and ductile fracture mechanism for metal sheets under plastic deformation are systematic studied, combining with the latest research results in the continuum damage mechanics, theoretical analysis, numerical simulations and experimental study for Al-alloy 5052BD-H14 and 5052P-H34.

In chapter 1, both the research background and purpose of this study will be introduced. The constitutive model is the fundamental to deal with its mechanics behavior, while the fracture criterion is the key technique to judge fracture. So, the conventional ductile fracture criteria are reviewed. Then the states of damage mechanics for metals based on $I_1-J_2-J_3$ framework are briefly reviewed. The main research contents and outline are also given in this chapter.

In chapter 2, by analyzing the behavior of metal containing voids under tension and shear deformation, the applicability of original Rousselier model is discussed. A modified Rousselier model is proposed by incorporating the recent extended damage evolution model by Nahshon and Hutchinson, in which the non-dimensional metric $\omega(\underline{\underline{\sigma}})$ (or Lode parameter) and the shear damage coefficient k_ω are employed. The physical meaning of the new damage evolution rule will also be interpreted in theory of probability. The analytical solution of the modified damage evolution equation under shear was obtained, and its ability to describe shear fracture of material is discussed.

In chapter 3, the numerical implementation of modified Rousselier model in finite element analysis (FEA) will be conducted. Firstly, the backward Euler scheme based stress integration algorithm will be briefly developed within

computational plasticity framework to solve the proposed model and the kernel derivation is carried out. Secondly, The integration algorithm is implemented and embedded into the commercial finite element software Abaqus/Explicit via its user material subroutine interface VUMAT by using Fortran coding language. Thirdly, some benchmark simulations will also be conducted to verify the stress integration algorithm and correspondingly developed program.

In chapter 4, the tensile tests of smooth round bar and notched round bars of Al-alloy 5052BD-H14 with different sizes were performed and the ductile fracture mechanism was analyzed by the macroscopic fracture phenomenon via scanning electron microscope. The mechanism can be concluded that the material failure under tension is caused by the nucleation, growth and coalescence of some micro-voids and micro-cracks. While for shear specimen, a shear fracture mechanism combining with void deformation was found. So that the kernel of damage evolution is the mechanical behavior of micro-voids under complex stress state. Consequently, the material parameters of the classical Rousselier model were identified by an inverse method using these experimental data. A shear test was also performed to calibrate the new shear damage coefficient in the modified Rousselier model. For the shear test, the simulations show that although shear failure can be predicted by the Rousselier model, the ductility was over-estimated. However, the modified Rousselier model can give more accurate results. The simulations on uniaxial tension of the round bars also confirm that the modified Rousselier model can well predict the cup-cone fracture mode. The results indicate that the Lode parameter in the new damage evolution model is important to capture the cup-cone fracture mode transition. The results show that the applicability of the constitutive model is improved for both tension and shear failure by the new material parameter k_{ω}.

In chapter 5, The ductile analysis of Al-alloy 5052P-H34 under different loading will be carried out by both physical experiments and numerical simulations. The physical failure modes were concluded and fracture mechanism was analyzed. Consequently, the material parameters were identified by an inverse method using these experimental data. A shear test was performed to calibrate the new shear damage coefficient k_{ω}. The Sandia test was also performed to verify the model's applicability. The crack path was investigated by the modified model, the results show that the fracture process and crack propagation under complex loading can be predicted by the modified model.

In conclusion, the ductile fracture mechanism of Al-alloy 5052BD-H14 and 5052P-H34 are studied by a modified Rousselier mode. The applicability of this model on shear failure is enhanced by the new damage evolution rule in which possible link-up of nearby voids under shear stress is considered. The simulation results show that the modified model can give more accurate results for both of the tension and shear failure.

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論文審査の結果の要旨

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学位論文題目

An experimental and numerical investigation on damage evolution and ductile fracture mechanism of aluminum alloy（アルミニウム合金の損傷評価及び延性破壊機構に関する実験及び数値的研究）

審査結果の要旨

本研究は，アルミニウム合金 5052BD-H14 及び 5052P-H34 について塑性変形に生じる損傷過程及び延性破壊機構を連続体損傷機構、理論的解析、数値シミュレーション、実験の観点から研究したものである。引っ張り及びせん断荷重下でのボイドを持つ金属の挙動を ROUSSELIER モデルを使って分析した。これまで知られているボイドの形成、成長、合体が引張過程で生じており、せん断過程では、ボイドの変形は認められた。本研究では、引張及びせん断荷重下の破壊機構を理論的、実験的に明らかにしたものである。

まず、アルミニウム合金 5052BD-H14 及び 5052P-H34 について塑性変形の損傷過程及び延性破壊機構を連続体損傷機構に基づき理論的解析あるいは実験的に明らかにしている。そこでは ROUSSELIER モデルを修正し、引っ張り過程のみならずせん断過程まで適用できるモデルを提示したところに彼自身の創意と工夫が見られる.

以上本研究は，アルミニウム合金の引張り及びせん断破壊のメカニズムを扱った優れた論文であり，本論文は博士（工学）の学位授与に値するものと判定する.