Title	Simple Finite Element Model to Study Influence of Microstructure upon Ductility of Duplex High Strength Steel
Author(s)	Murakawa, Hidekazu; Serizawa, Hisashi; Katayama, Kazuaki
Citation	Transactions of JWRI. 2007, 36(2), p. 67-71
Version Type	VoR
URL	https://doi.org/10.18910/9197
rights	
Note	

Simple Finite Element Model to Study Influence of Microstructure upon Ductility of Duplex High Strength Steel †

MURAKAWA Hidekazu*, SERIZAWA Hisashi** and KATAYAMA Kazuaki***

Abstract

In the development of superior high strength - high toughness welding steel materials, a balance between strength and toughness is necessary. A numerical study is carried out to clarify the influence of micro structure on strength and toughness and to establish a concept of strength - toughness balance. The effect of phase transformation, yielding behavior and crack growth on maximum strength of a plate with initial cracks is investigated. It is shown that expansion during phase transformation may increase brittle fracture strength. Two failure modes are distinguished, a plastic deformation dominant failure mode associated with low plastic strength, and a crack growth dominant failure mode associated with high plastic strength. A concept of strength toughness balance is proposed in which plastic strength and surface energy have values in the transition between these two failure modes where maximum joint strength is observed.

KEY WORDS: (Finite Element Method) (Martensite Transformation) (Volumetric Change) (Interface Element) (Crack growth)

1. Introduction

In the development of superior high strength - high toughness welding steels, a balance between strength and toughness is necessary. To clarify the influence of micro structure on strength and toughness and to establish a concept of strength - toughness balance, a numerical study was carried out. In this study a 2-D finite element model is considered, in which crack growth and volumetric expansion due to phase transformation are considered using a very simple model. In the following, the modeling outline and obtained results are reported.

2. Modeling Outline

Crack growth is modeled using the "Interface Elements"[1] proposed based on the concept that crack growth is the process in which new surfaces are formed. In this method distributed nonlinear springs are arranged along potential crack surfaces as shown in **Fig.1(a)** and **(b)**. The interaction between crack surfaces is characterized by a surface potential function that involves the surface energy γ and the scale parameter r_0 as described in **Fig.1(c)**. Volumetric expansion due to phase transformation is considered as the initial strain or the inherent strain.

3. Influence of Phase Transformation on Brittle Fracture

In this study, it is assumed that transformation from austenite to martensite occurs in a finite element when the mean stress in the element exceeds a critical value σ_{cr}. Associated volumetric expansion strain is assumed to be the value corresponding to $\alpha \cdot \sigma_{cr}$ where α is a parameter that expresses the extent of expansion. Fictitious values of material properties are adopted in order to clarify the behavior.

Figure 2 shows the model used in the investigation. It is a small plate 2 mm x 1 mm (with a unit thickness) with a center crack 0.6 mm in length. The problem is assumed to be a plane stress two dimensional problem. Young's modulus and Poisson's ratio are 200 GPa and 0.3, respectively. The surface energy γ is determined from the value of K_{IC} which is assumed to be 60 $MPa \cdot m^{1/2}$. The scale parameter r_0 is assumed to be 0.001 mm. The size of the element at the crack tip is 0.001 x 0.001 mm. Figure 2 shows the applied load, deformed shape, mean stress at crack tip and austenite ($\tilde{\gamma}$) martensite (α) distribution for σ_{cr} = 3000 MPa and α = 0,

† Received on December 14, 2007

* Professor
** Associate Professor
*** Graduate Student

Transactions of JWRI is published by Joining and Welding Research Institute of Osaka University, Ibaraki, Osaka 567-0047, Japan.

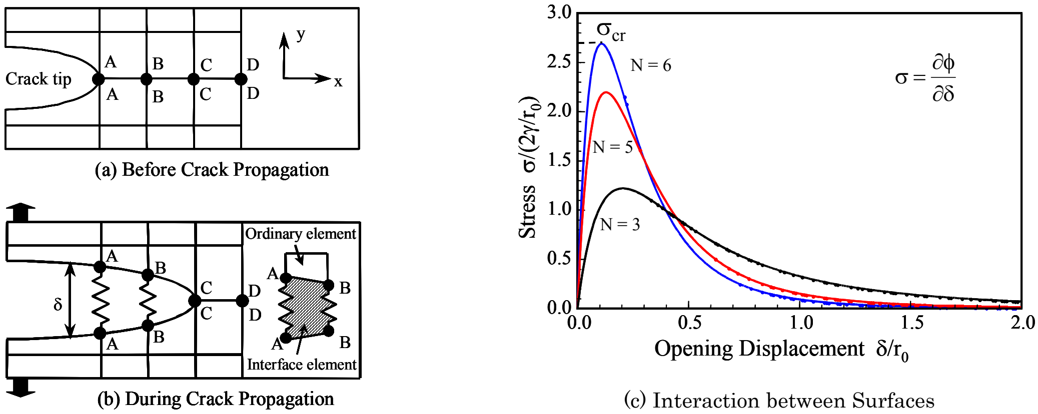


Fig.1 Outline of the "Interface Element".

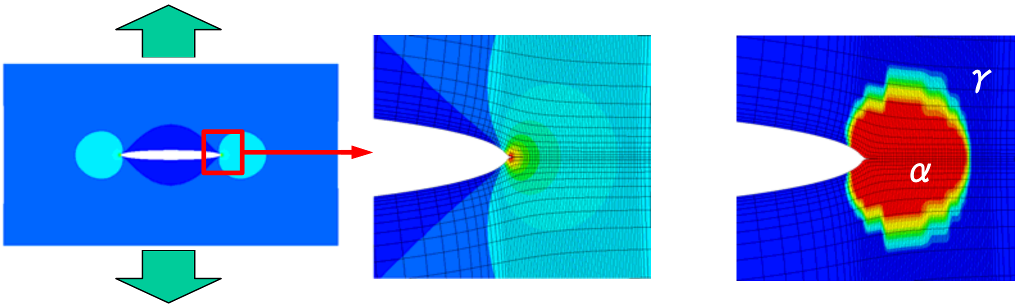


Fig.2 Model, applied load, deformed shape, mean stress at crack tip and austenite γ (Blue) – martensite α (Red) distribution for σ_{cr} = 3000 MPa and α= 0.

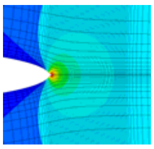
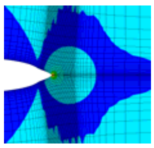
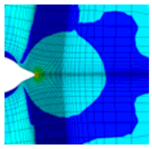
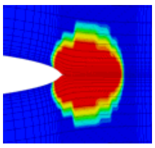
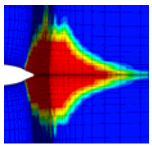
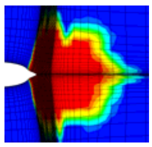
Model (σ_{cr} = 3000MPa)	α = 0 No Expansion	α = 3 Expansion	α = 6 Expansion
Mean Stress Distribution Red = Ten Blue = Comp			
Phase distribution Red = Martensite Blue = Austenite			

Fig.3 Comparison among cases with expansion parameter α = 0, 3 and 6.

that is, no expansion due to phase transformation at the moment of failure.

Figure 3 shows a comparison among cases with the expansion parameter α = 0, 3 and 6; and **Fig.4** shows the load displacement relationship and maximum strength in each case. From these figures it may be seen that expansion caused by phase transformation increases brittle fracture strength.

4. Influence of Yield Stress, Strain Hardening and Surface Energy on Ductility

A series of computations was conducted with different values of yield stress assuming that the surface energy γ is constant. The material is assumed to be elastic-plastic without strain hardening. In these computations, the yield stress is changed from 13,000 MPa, to 30,000 MPa. Such unrealistic values are selected in order to understand the trend of the phenomena. As shown in **Fig.5**, when the yield stress is small, as in the case of 13,000 MPa, the plate fails in a full plastic mode. When the yield stress is equal to or larger than 15,000 MPa, it fails in a brittle manner. Failure load decreases with the increase of yield stress. This agrees with the common understanding that the material becomes brittle when the hardness is high.

The relationship between failure load and yield

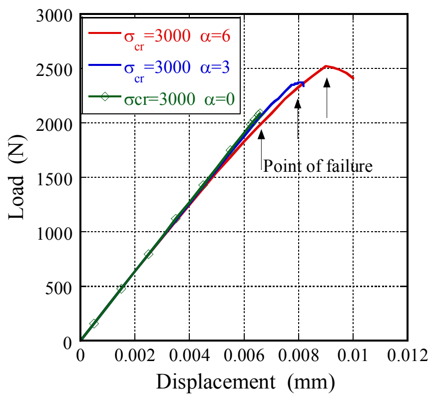


Fig.4 Load displacement relationship and brittle fracture strength.

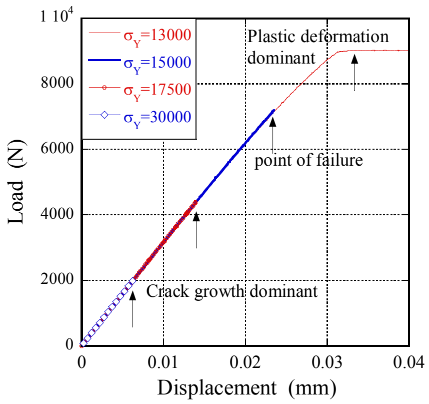


Fig.5 Load displacement relationship with different values of yield stress.

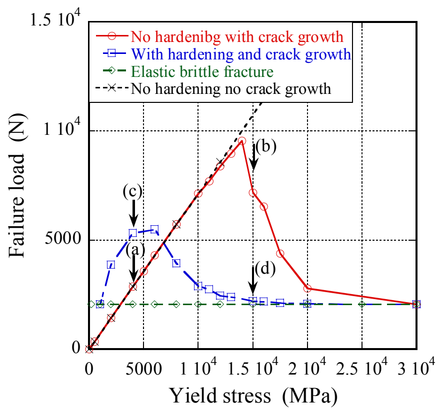


Fig.6 Failure load of cases with different values of yield stress and strain hardening.

stress is summarized in **Fig.6**. To understand the influence of strain hardening, two cases, namely with and without strain hardening are considered. As references, a curve for elastic-perfectly-plastic material without crack growth in which the surface energy is infinitely large, and another for elastic plate with crack growth are also plotted. As it may be seen in Fig.6, when the yield stress is small, failure load increases with the

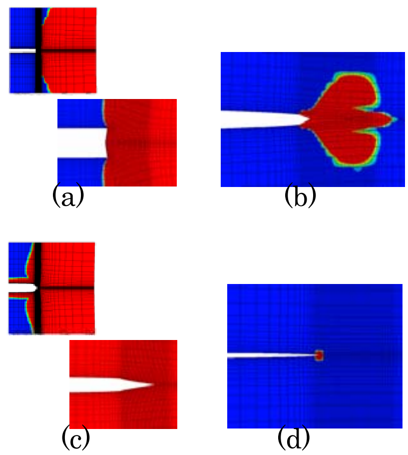


Fig.7 Deformation and distribution of plastic strain at failure.

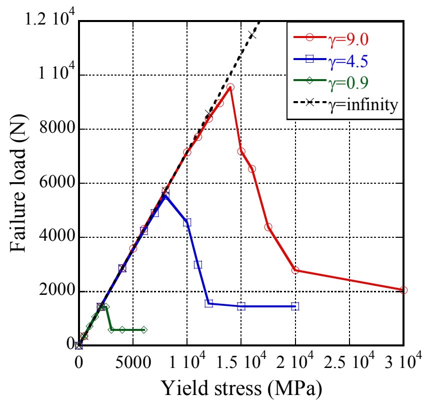


Fig.8 Influence of surface energy γ on failure strength.

yield stress and the curves for elastic-perfectly-plastic material with and without crack growth coincide. Here the phenomenon is plastic deformation dominant. When the yield stress is large, failure load approaches that of brittle fracture of elastic plate. Here the phenomenon is crack growth dominant. It is clearly seen that there is an optimum value of yield stress which gives the maximum failure strength. However, this value may change with the size of the structure and the size of existing cracks.

In Fig.6, it may be also seen that failure strength increases with strain hardening when the phenomena is plastic deformation dominant, but decreases in the crack growth dominant region.

Deformation and distribution of plastic strain at failure are shown in **Figs.7(a)** and **7(b)** for plastic deformation dominant (σ_Y = 4,000 MPa, point (a) in Fig.6) and crack growth dominant (σ_Y = 15,000 MPa, point (b) in Fig.6) cases. As may be seen in the figures, significant crack growth is not observed when the yield stress is small. On the other hand, when the yield stress is large, the plate fails with both plastic deformation and crack growth. The same comparison for cases with strain hardening is shown in **Figs.7(c)** and **7(d)**. When the yield

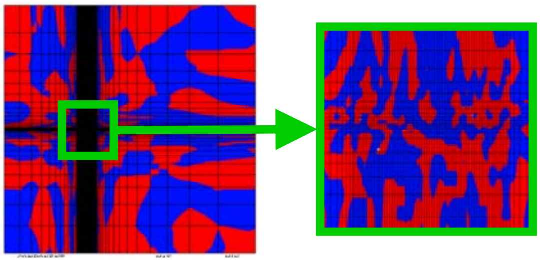


Fig.9 Distribution of crystals.

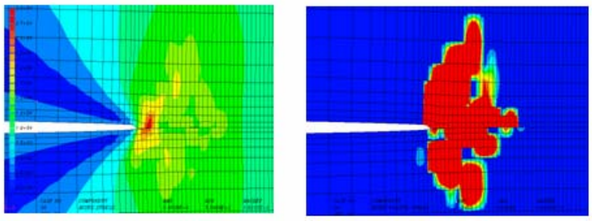


Fig.10 Distribution of Mises stress and plastic strain.

stress is 4,000 MPa, point (c) in Fig.6, the failure mode becomes a combined mode due to strain hardening. When the yield stress is 15,000 MPa point (d) in Fig.6, only small scale yielding is observed.

The influence of surface energy γ is shown in **Fig.8**. Cases with three different values of surface energy, namely 9.0, 4.5 and 0.9 N·mm/mm^2 are compared. As references, a curve for elastic-perfectly-plastic material without crack growth is also plotted as before. As it is expected, failure strength increases as surface energy increases.

5. Failure of Polycrystalline Isotropic Elastic-Plastic Material

A preliminary study to understand the failure of polycrystalline materials is carried out. Two types of crystals are distributed at random with a ratio 50/50 % in the same plate with a crack used above. **Figure 9** shows the distribution of the two different types of crystals.

Figures 10(a) and **(b)** show the distributions of Mises stress and plastic strain respectively at failure when the plate is subjected to tension and the values of yield stress are 5,000 MPa and 10,000 MPa in this case. **Figure 11** shows the load displacement relationship of 3 cases, 100 % high strength material, 50/50 % and 100 % low strength materials. It may be seen that failure is plastic deformation dominant and that the value of failure load of the 50/50 % case is very close to that of the 100 % low strength crystals.

Figure 12 shows the load displacement relationship of 3 cases, 100 % high strength material, 50/50 % and 100 % low strength materials when yield stress values of 15,000 and 30,000 MPa (crack growth dominant) are adopted. It may be seen that the failure load here follows the ratio of the two types of crystals.

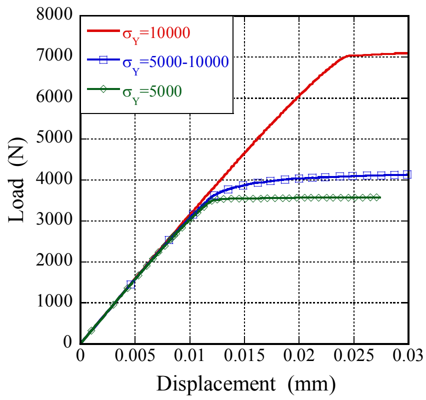


Fig.11 Load displacement relationship for plastic deformation dominant failure.

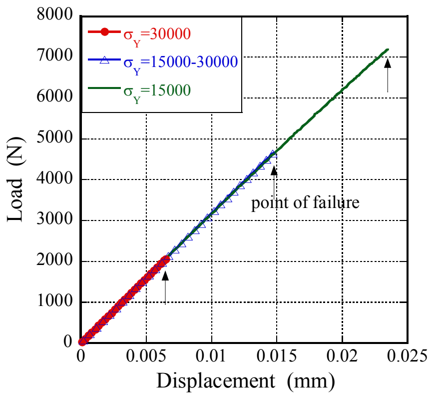


Fig.12 Load displacement relationship for crack growth dominant failure.

6. Conclusions

(1) To study the influence of micro structure of steel on strength and toughness, a two dimensional finite element model was developed in which crack growth and volumetric expansion due to phase transformation were considered.

(2) It is shown that volumetric expansion due to the phase transformation may increase the brittle fracture strength.

(3) When the surface energy is assumed to be constant, the failure mode changes from a plastic deformation dominant mode to a crack growth dominant mode with the increase of the yield stress. It is also found that the strength becomes a maximum when the yield stress has a value in the transition between the two failure modes.

References

1) H. Murakawa, H. Serizawa, K. Miyamoto, I. Oda, "Strength of Joint Between Dissimilar Elastic Materials," Proceedings of 2003 International Conference on Computational & Experimental Engineering & Sciences (ICCES'03), 6 (2003) (CD-ROM).