2009年　1月　16日

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Title	Discrete Dislocation Dynamics Approach to Dynamic Fracture Toughness under Short Pulse Loading

(800 words)

The effect of loading rate on both cleavage and dimple fracture mechanisms had been experimentally investigated by the previous researchers. The crack initiation of both cleavage and dimple fracture was sensitive with the short life of impulsive loading. The dynamic fracture toughness was measured for several materials and it was shown that the dynamic fracture toughness was remarkably increased when the duration of impulsive stress intensity is shorter than 20 μs.

Experimental results of the cleavage fracture from a crack tip in welding structure steel SM50A indicated that the remarkable increase in dynamic fracture toughness was obtained under the short pulse loading or high loading rate, for instance, with the duration of less than 20 μs. It is obviously contrary to the usual understanding that the higher yield strength the lower the fracture toughness is.

The same trend of the fracture toughness was also obtained by the experiment of aluminum alloy 7075-T651, in which dimple fracture was dominant. This material is insensitive against loading rate. The dimple fracture mechanism model indicates that a dominant void plays an important role on the dimple fracture initiation. The crack initiation is a result of coalescence between a dominant void and a crack tip. The coalescence is caused by nucleation of many fine voids in the inner ligament and their subsequent linkage.

This work is carried out to explain and obtain the physical meaning of the remarkable increase in both the cleavage and the dimple fracture under short pulse loading as mentioned above. Discrete dislocation dynamics (DDD) method is utilized to construct models of the cleavage and dimple fracture initiation. Since, in both of the cleavage and the dimple fracture mechanisms, mobility of dislocations plays an important role on the initiation of crack. In addition, especially under dynamic loading, dynamic crack behavior can be simply treated by the DDD method.

The dynamic plasticity ahead of the crack tip in mode I condition is experimentally measured for the low alloy carbon steel JIS SM490A by using the one-point bend test at room temperature. Three different lengths of specimens are used to generate 25, 50 and 100 μs pulse durations. The experimental results of the stretched zone width are used to calculate the crack tip opening displacement

(CTOD) and it is indicated that the CTOD decreases with the pulse duration for the same amplitude of dynamic stress intensity pulse. CTOD is proportional to square of applied stress intensity as seen in linear elastic fracture mechanics. The numerical analysis is carried out by a DDD model. The obtained dislocation array parameters such as the number of dislocations, dislocation distribution density, crack tip opening displacement and plastic zone size increase with the magnitude of stress intensity factor, K_I and pulse duration. The validity of the DDD model is proven by the good agreement between the numerical results and the experimental ones.

Following the investigation on plasticity, the specimens of the same material are chilled at low temperature of -80^{0}C to examine the cleavage fracture. The remarkable increase in the dynamic fracture toughness value, K_{Id} is obtained under high loading rate or short pulse duration. The value of CTOD is also closely correlated with K_{Id}. The distance from the crack tip to the cleavage origin is almost independent of the pulse duration and equal to around 100 μm. The numerical simulation to the experiment is carried out by the discrete dislocation dynamics model of cleavage fracture considering the pile-up of dislocations. The time effect on dynamic yield strength can be estimated by the previous experimental results of dynamic plasticity. The numerical results are compared with the experimental ones in reasonable agreement.

Dimple fracture of aluminum alloy 7075-T651 subjected to various stress intensity pulses with durations of 20, 40 and 80 μs is investigated by combination of discrete dislocation dynamics and the Gurson-Tvergaard-Needleman constitutive model (GTN-model). A dominant void ahead of a macro crack tip is modeled by a micro crack. The time evolution of principal stress components along the inner ligament is computed by the sum of the crack tip stress field and the interaction stress field of dislocations emitted from both the micro crack and the macro crack. The yielding flow of GTN-model is used to estimate void volume fraction, which is used for a fracture initiation criterion. The numerical results of the dimple fracture are obtained in a reasonable agreement with the experimental ones.