Interaction Potential between a Dislocation and a Pinning Atom in FCC Metals

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Abstract. Amplitude dependent internal friction (ADIF) was measured on 4N and 6N Cu crystals at 4K–40 K to study the interaction between a dislocation and a pinning atom. The temperature dependence of the stress amplitude necessary to produce a constant ADIF was well explained by assuming the Cottrell type interaction potential based on linear elasticity. This is clearly different from the case of Al crystals where it was necessary to consider a modified Cottrell potential including a deviation from linear elasticity near the dislocation center.

Introduction

Plastic property of metal crystals is one of the most important properties for mechanical supporting materials. One must consider the hardness and the plasticity for 'realistic strength'. Introducing foreign atoms in the solvent metal allows one to control the balance between them, because impurity atoms resist to the motion of crystal dislocations. For this reason, it is interesting to obtain detailed information on the interaction between a dislocation and a pinning atom

Amplitude dependent internal friction (ADIF) measurement can be used for investigating the interaction between a dislocation and a pinning atom. When the dislocation moves on the slip plane, an impurity atom in the nearest atomic plane mainly resists the motion (Fig 1). When the applied stress is increased to a critical value, the dislocation unpins from the impurity atom. An alternating stress produces a hysteresis mechanical loss, i.e., ADIF. The stress amplitude to produce a constant ADIF is changed with temperature by thermal activated motion of dislocations. Thus the interaction potential or interaction force between them is studied by measuring the ADIF with temperature change (Fig. 2).

Indenbom and Chernov first suggested the possibility of measuring force distance curve between dislocation and impurity atom by ADIF[1]. Schwarz and Granato first showed the $-T^{2/3}$

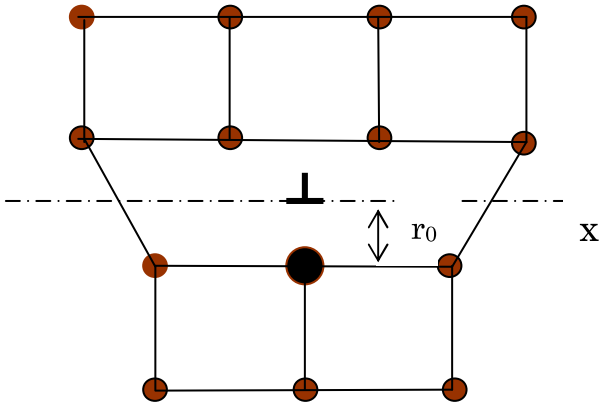

Fig. 1. Edge dislocation and foreign atom.
The dislocation moves to x direction. (above)

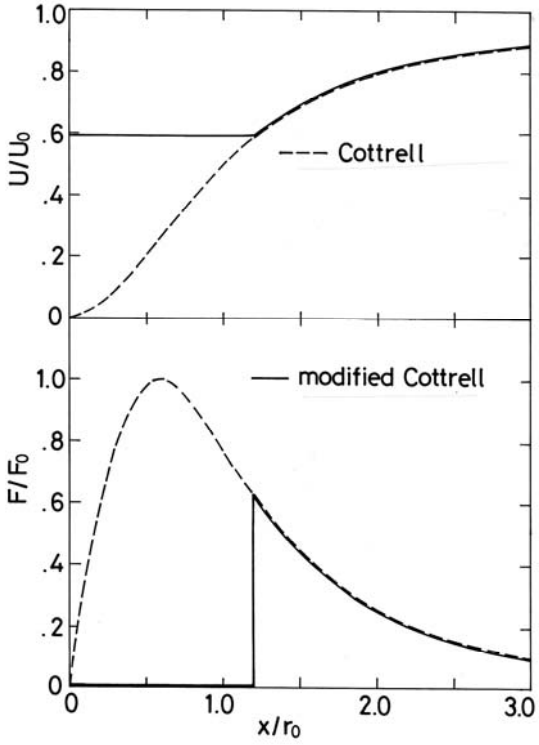

Fig. 2. Cottrell type potential U and force F (broken line) profile and a modified Cottrell potential profile (real line) vs. the distance between a dislocation and pinning atom. (right)

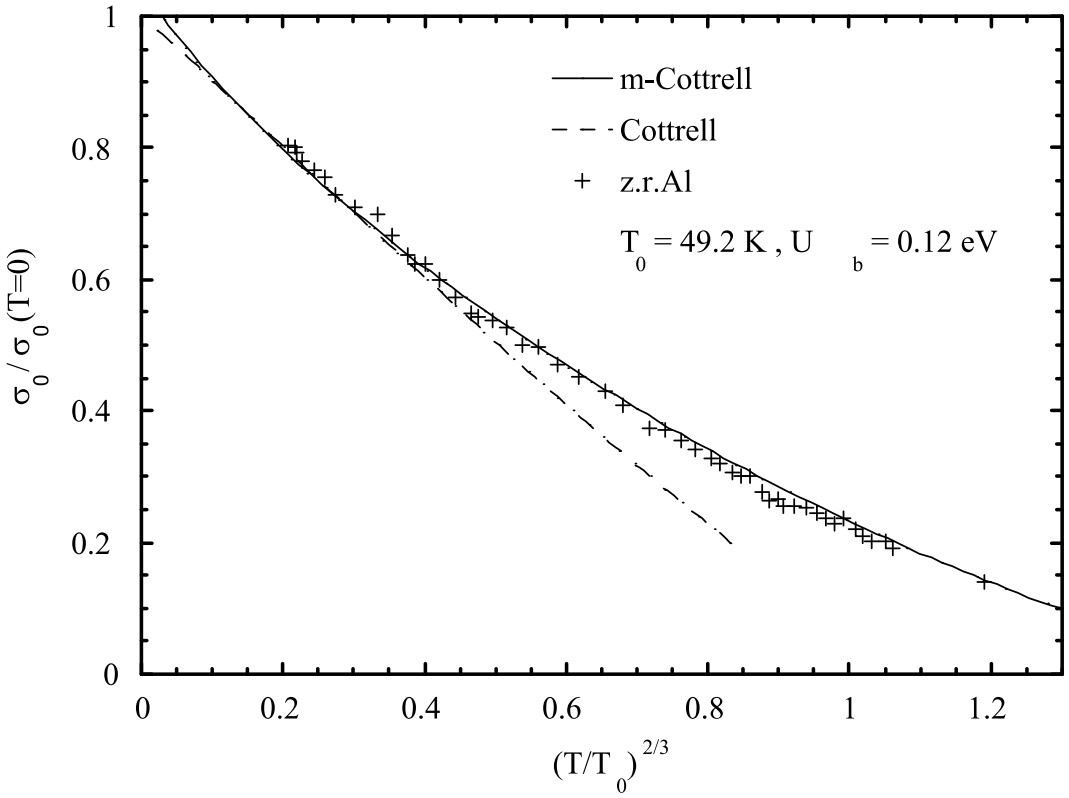

Fig. 3. The temperature dependence of stress amplitude in zone refined aluminum for producing the constant ADIF. The stress amplitude and temperature are normalized by extrapolated values of $T^{2/3}$ dependence at lower temperature.

dependence of strain amplitude for constant ADIF at very low temperature in Al crystal [2]. Kosugi and Kino measured the ADIF of several different aluminum dilute alloys at low temperature, and find that the temperature dependence of stress amplitude necessary to produce a constant ADIF is common to different solute atoms, although the magnitude of the stress change with temperature is different, e.g., by nearly two times between Cu and Zn [3]. They also show that the temperature dependence cannot be explained by the Cottrell type potential based on linear elasticity, but can be explained by a modified Cottrell potential proposed by the authors (Fig. 2).

Gremaud refers to their result in his chapter [4] and comments that information on the interaction force between a dislocation and a pinning atom can be measured by ADIF at low temperatures. But he considers that the deviation from the $T^{2/3}$ dependence at higher temperature in their result should be due to a long-range interaction between dislocations and solute atoms.

In this paper, we would like to show two things, which will confirm high possibilities of ADIF. First is the result for a high purity Al, where the stress amplitude is measured in a wide range, i.e., down to 15% of the stress at 0K. Second is the measurement for Cu crystals, which should be compared with that for Al crystals with much interest.

Experiment and Discussion

Internal friction was measured by a composite oscillator method using -18.5° X-cut quartz (50 x 3.5 x 3.5 mm, resonance frequency f =51 kHz at room temperature).

(i) zone refined aluminum (z. r. Al)

ADIF should be measured in a wide range of stress to confirm the model potential. At higher temperature, stress amplitude for a constant ADIF becomes lower by thermal activation. In such a case, dislocation unpinning from a single pinning atom becomes difficult to occur for a short double loop and simultaneous unpinning from several atoms for a longer triple loop will occur. In fact, a deviation of the stress amplitude from that predicted by a modified Cottrell potential is observed below 40% of stress at 0K in Al dilute alloys (25ppm Mg, 50ppm Ag), which is explained by simultaneous unpinning [5]. A zone refined Al crystal has only 1ppm impurity atoms and is expected to be one of the best samples to check the reality of the potential model. The sample is 50 x 3.5 x 3.5 mm in size, and was annealed in air at 673 K for 3h before measurement. Fig. 3 shows the result. The temperature dependence is explained satisfactorily by modified a Cottrell potential down to 15% of stress at 0K.

(ii) Cu crystals

We measured 6N Cu and 4N Cu crystals (Figs. 3- 5). A 6N Cu crystal ingot was supplied from Nippon Mining Co. The sample was cut by spark erosion, and the size is 33 x 2.5 x 2.5 mm.

6N Cu sample was annealed in vacuum at 1073 K for 10h before measurement. The resistivity ratio is about 3600. Oxygen-free 4N Cu was crystallized by Bridgman method in Ar atmosphere [6]. The ingot was annealed in vacuum at 973 K for 24h. The sample was cut by spark erosion before measurement. The size is 36 x 3.0 x3.0 mm.

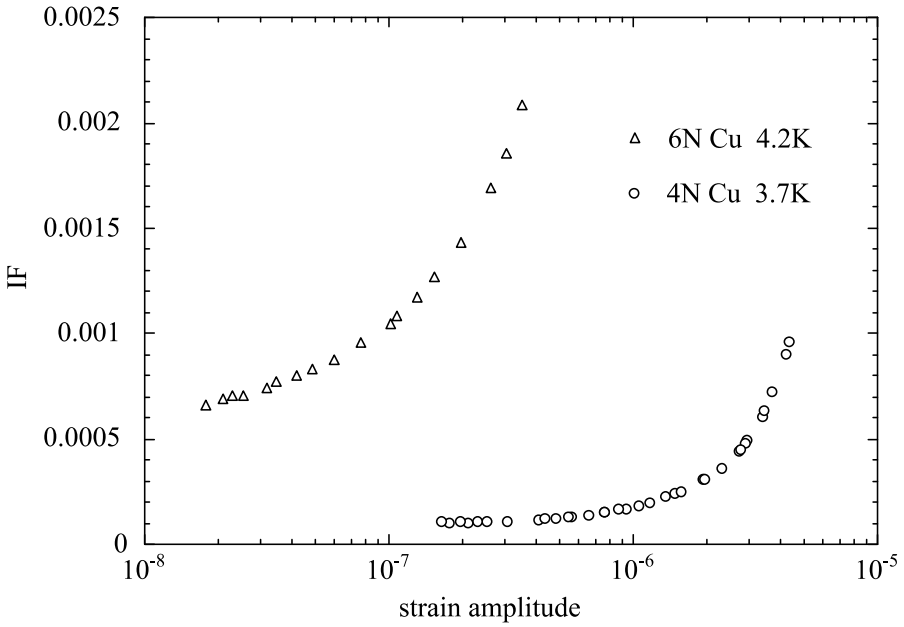

Fig. 4. Internal friction vs. strain amplitude in Cu crystals at 4 K.

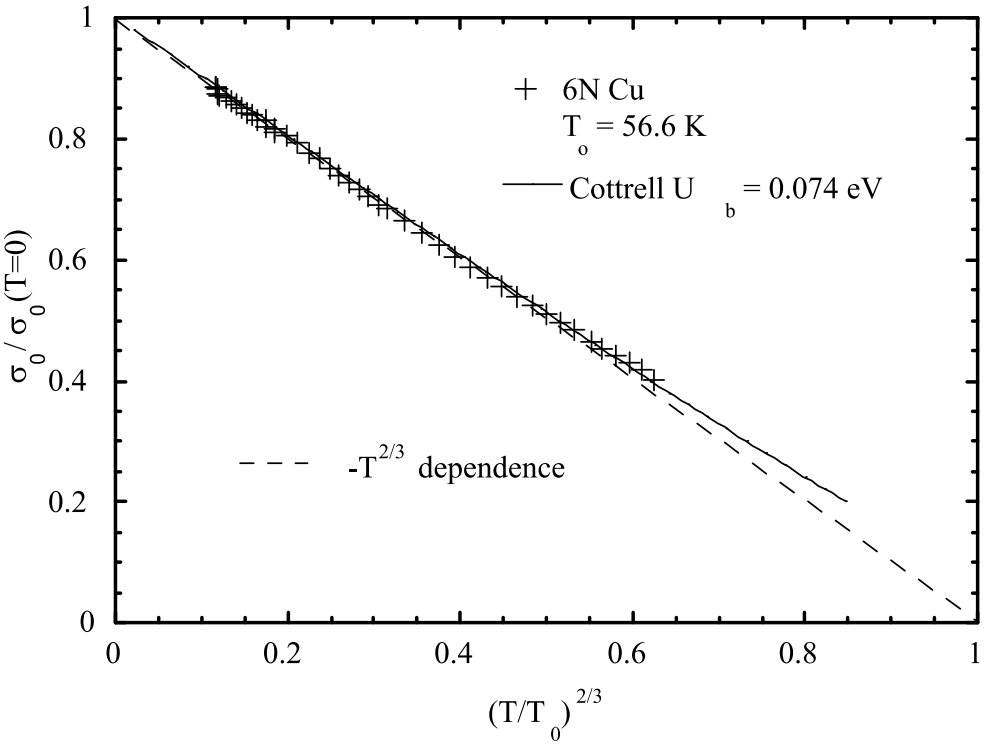

Fig. 5. The temperature dependence of the stress amplitude in 6N Cu necessary to produce a constant ADIF. The stress amplitude and temperature are normalized by extrapolated values of $T^{2/3}$ dependence at low temperature.

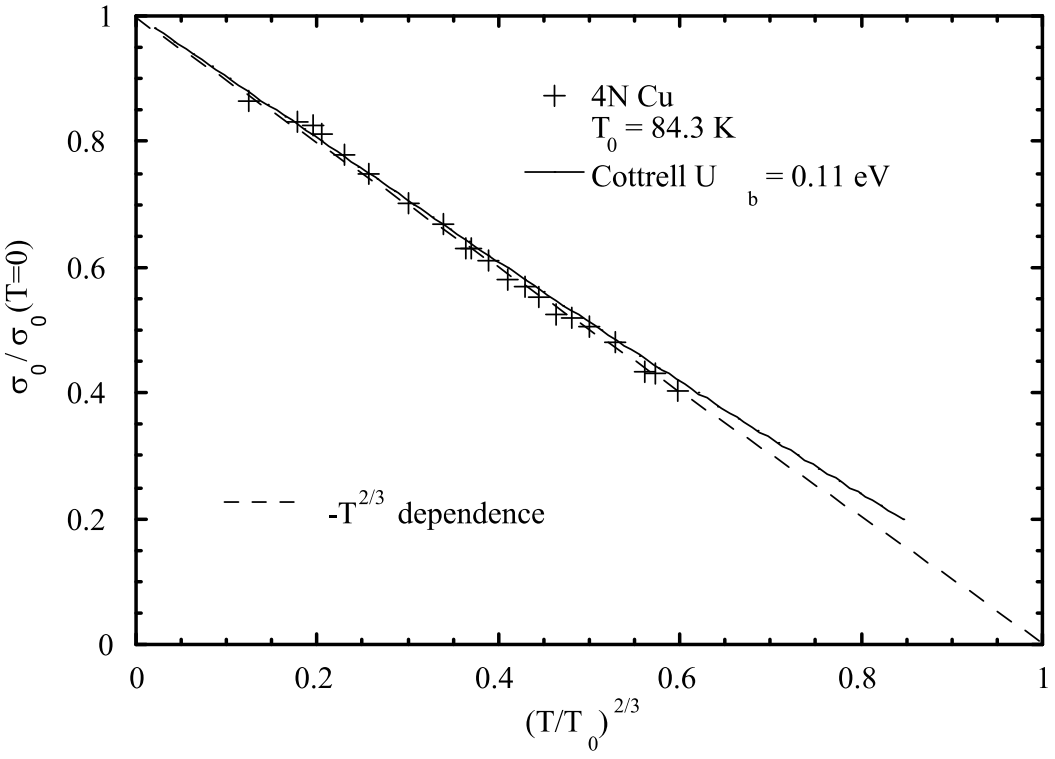

Fig. 6. The temperature dependence of stress amplitude in 4N Cu for producing the constant ADIF. The stress amplitude and temperature are normalized by extrapolated values of $T^{2/3}$ dependence at low temperature.

Fig. 4 shows the internal friction (= πQ^{-1}) vs strain amplitude at 4 K. The amplitude dependence starts from the range of 10^{-8} of strain for 6N Cu and from $5x10^{-7}$ for 4N Cu. The temperature dependence of strain amplitude for a constant ADIF was measured between 4K and 40K. Above 40K internal friction becomes very large, and difficult to measure by our method.

Although the magnitude of stress change with temperature is different between two samples, i.e., the different T_0, the dependence is almost the same for two crystals and is well explained by assuming a Cottrell type potential based on linear elasticity.

Clounet calculated the edge dislocation-vacancy interaction in FCC metals by atomic simulation [7]. His results show that vacancy is most stable just above the site of extra half plane edge, and the interaction profile of Cu is well approximated by the calculation using linear elasticity, while the interaction profile of Al is rather different from that of linear elasticity especially near the dislocation center. His computer simulation results agree to our results.

Conclusion

1. The temperature dependence of stress amplitude to produce a constant ADIF is found to be different between Al crystals and Cu crystals.
2. The different temperature dependence is considered to be due to the difference of interaction potential form or interaction force-distance curve profile of a dislocation with a pinning atom in Al and in Cu.
3. It is found from ADIF measurement that linear elasticity is a good approximation near dislocation center in Cu, while linear elasticity is no more good approximation near dislocation center in Al.

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