Supplementary Material

for

Elucidating the origin of electroplasticity in metallic materials

Moon-Jo Kim[1†], Sangmoon Yoon[2†], Siwook Park[2], Hye-Jin Jeong[2], Ju-Won Park[2], Kuntae Kim[2], Janghyun Jo[2], Taehoon Heo[3], Sung-Tae Hong[4], Seung Hyun Cho[5], Young-Kyun Kwon[6], In-Suk Choi[2], Miyoung Kim[2], and Heung Nam Han[2]*

[1]*Shape Manufacturing R&D Department, Korea Institute of Industrial Technology, Incheon 21999, Republic of Korea.*

[2]*Department of Material Science and Engineering & Research Institute of Advanced Materials, Seoul National University, Seoul 08826, Republic of Korea.*

[3]*Production Engineering Group, Hyundai Steel Co Ltd, Dangjin 31719, Republic of Korea.*

[4]*School of Mechanical Engineering, University of Ulsan, Ulsan 44610, Republic of Korea.*

[5]*Safety Measurement Center, Korea Research Institute of Standards and Science, Daejeon 34113 Republic of Korea.*

[6]*Department of Physics and Research Institute for Basic Sciences, Kyung Hee University, Seoul 02447, Republic of Korea.*

*Correspondence to: hnhan@snu.ac.kr (H.N.H.)

† These authors contributed equally to this work.

1. Charge imbalance at the grain boundary in FE simulation: Case study

In the main text, the electrical conductivity of the grain boundary was considered to be 1/10 that of the grain interior (Case 1). Here, we considered two additional cases of grain boundaries with lower electrical conductivities: 1/100 and 1/1000 that of the grain interior as Case 2 and Case 3, respectively. The electric current density was set to 110 A/mm^2 and applied for 0.5 s in all cases. In Case 1, as discussed in main text, no noticeable temperature gradients were seen in FE simulations due to the rapid heat conduction. This observation did not change in Cases 2 and 3. Note the obvious distribution of electric current density seen at the grain boundary region (Fig. S1), even though no temperature gradient was observed (Fig. S2).

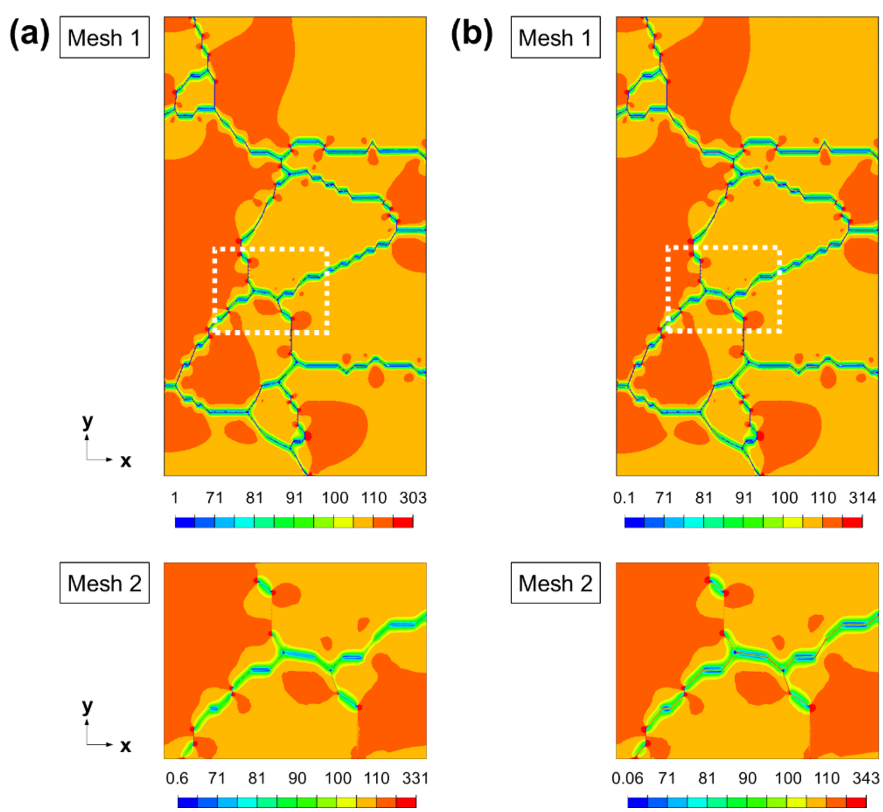

Figure S1. Contour maps of electric current density: (a) Case 2 and (b) Case 3. The area marked with a dotted line in white on Mesh 2 is the region of Mesh 3. The direction of electric current is +y direction.

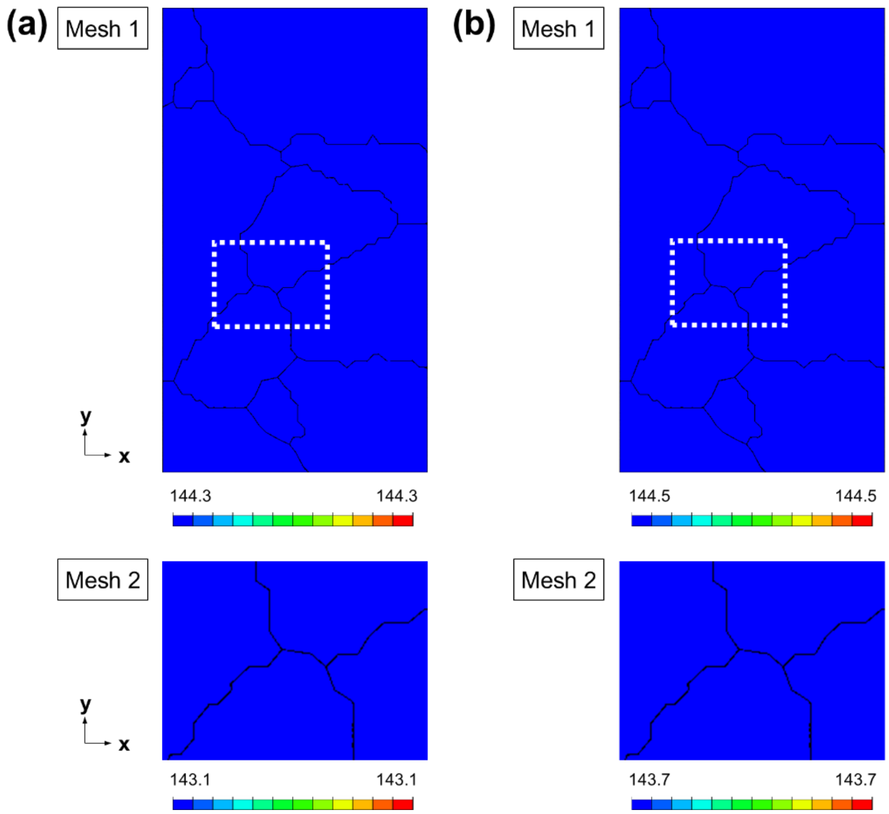

Figure S2. Contour map of temperature: (a) Case 2 and (b) Case 3. The area marked with a dotted line in white on Mesh 2 is the region of Mesh 3. The direction of electric current is +y. For convenience, grain boundaries are superimposed on the contour map of each model.

However, these thicknesses of the grain boundary were still overestimated compared to generally accepted levels. To describe a realistic thickness of the grain boundary, Mesh 3 was constructed by scaling down Mesh 2 For Mesh 1, Mesh 2, and Mesh 3, the thicknesses of the grain boundary were considered to be 100 nm, 20 nm, and 2 nm, respectively. As in the cases of

Mesh 1 and Mesh 2, the results of FE analysis with Mesh 3 also showed that the charge imbalance at the grain boundary increased as its electrical resistivity increased, although no temperature gradient was found (Fig. S3).

In order to check the temperature gradient between the grain interior and grain boundary under the electric current, temperature distribution was verified in microsecond units (10^{-6} s) as attached as Movie S1. As mentioned in the main text, it was confirmed that no temperature gradient was observed due to rapid heat conduction at the microscale level.

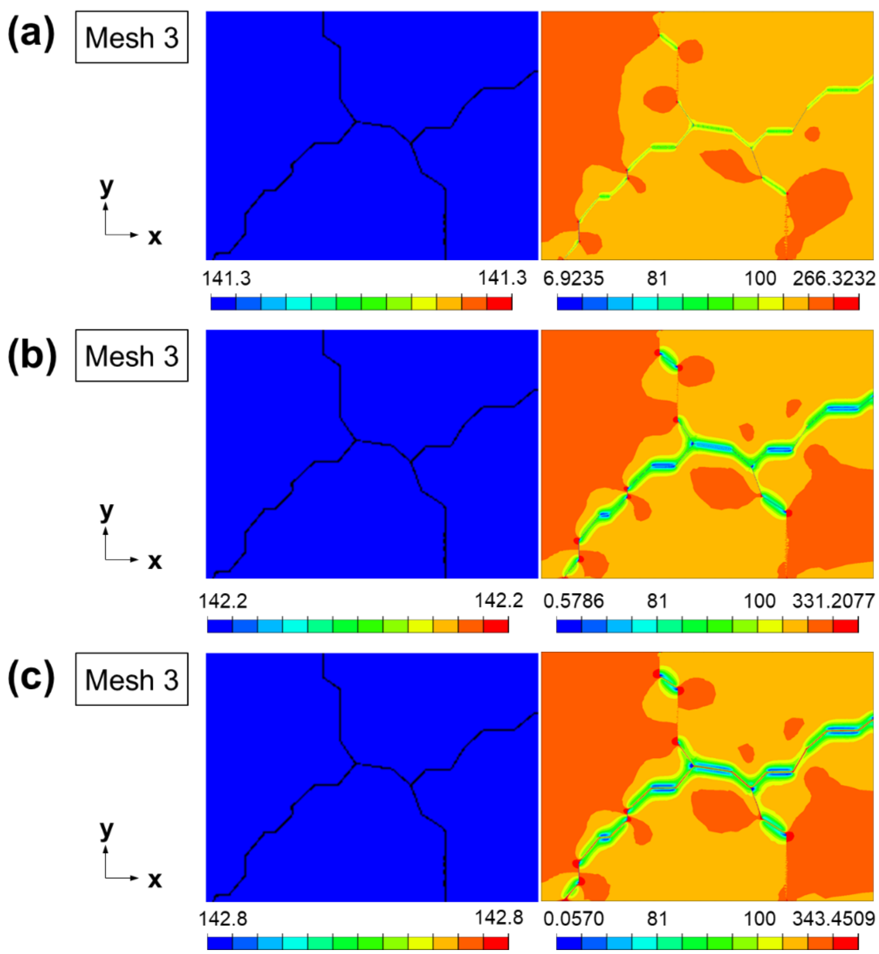

Figure S3. Contour map of nodal temperature (left) and electric current density (right) in Mesh 3. The calculation conditions are (a) Case 1, (b) Case 2, and (c) Case 3. The direction of electric current is +y direction. For convenience, grain boundaries are superimposed on the contour map of each model.

Movie S1. Contour map of temperature (left) and electric current density (right) in Mesh 2 under application of electric current in FE analysis in microsecond units (10^{-6} s).

2. Temperature dependence on elastic modulus

Figure S4 shows the temperature dependences of elastic modulus for aluminium alloys and magnesium alloys. It was measured using a hot plate to consider thermal effect on elastic modulus. The temperature dependences of elastic modulus for each alloy were found to be similar to values in the literature [1,2].

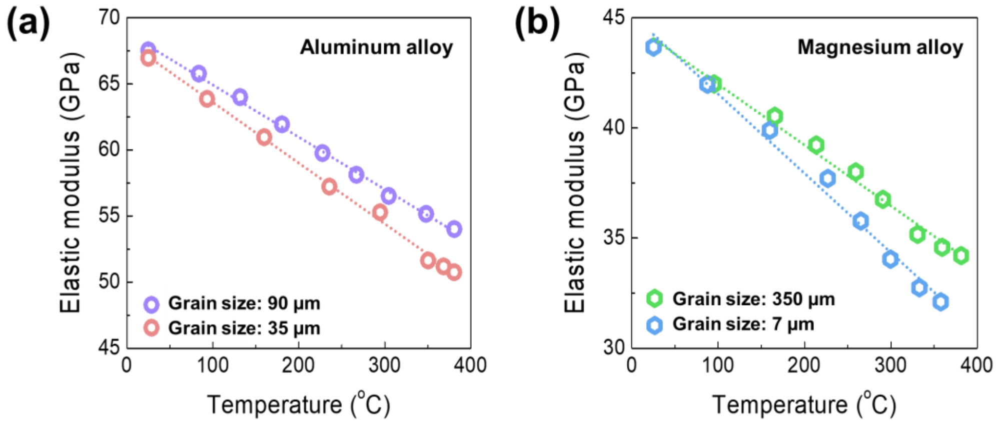

Figure S4. Temperature dependence on elastic modulus of: (a) aluminum alloy and (b) magnesium alloy. The symbols represent experimental data and the dotted lines indicate the linear relationship between elastic modulus and temperature.

References

[1] R.B. Mclellan, T. Ishikawa, J. Phys. Chem. Solids 48 (1987) 603–606.

[2] H. Watanabe, T. Mukai, M. Sugioka, K. Ishikawa, Scr. Mater. 51 (2004) 291–295.