Pulsed Steels

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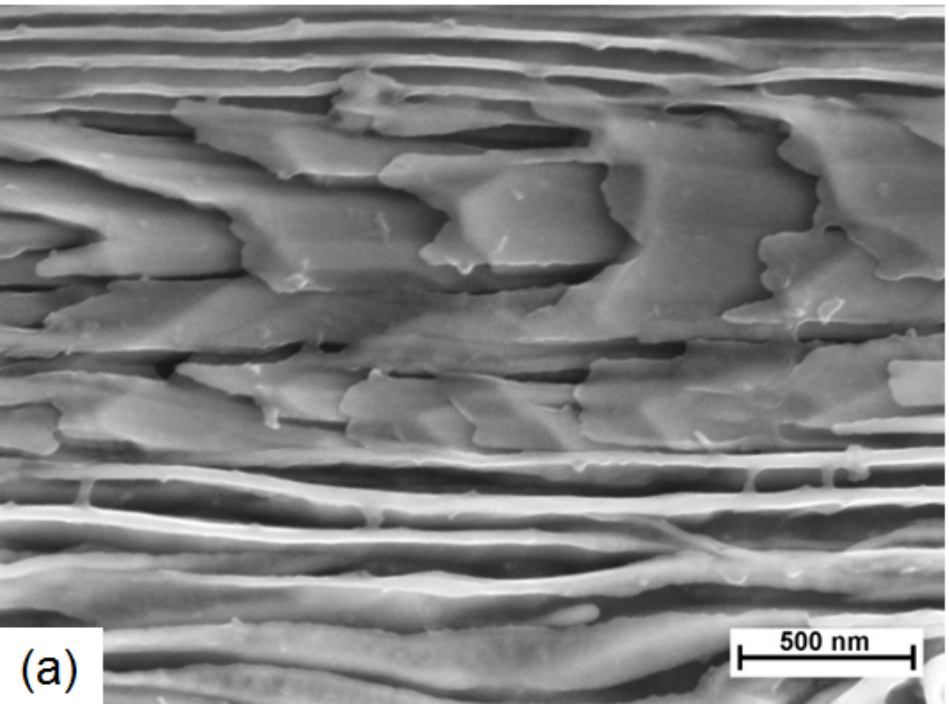
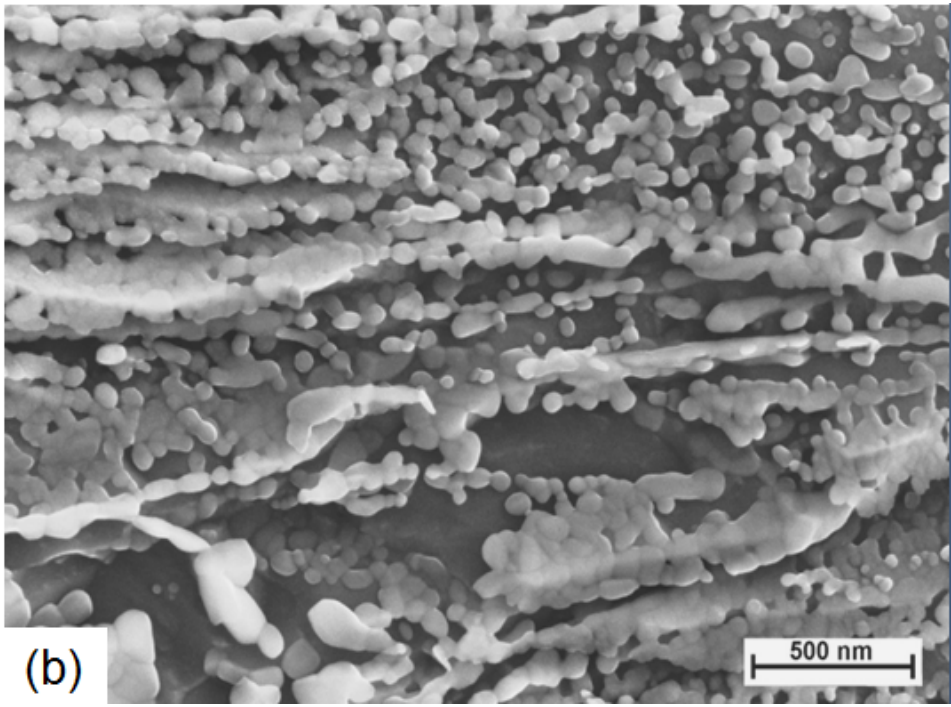
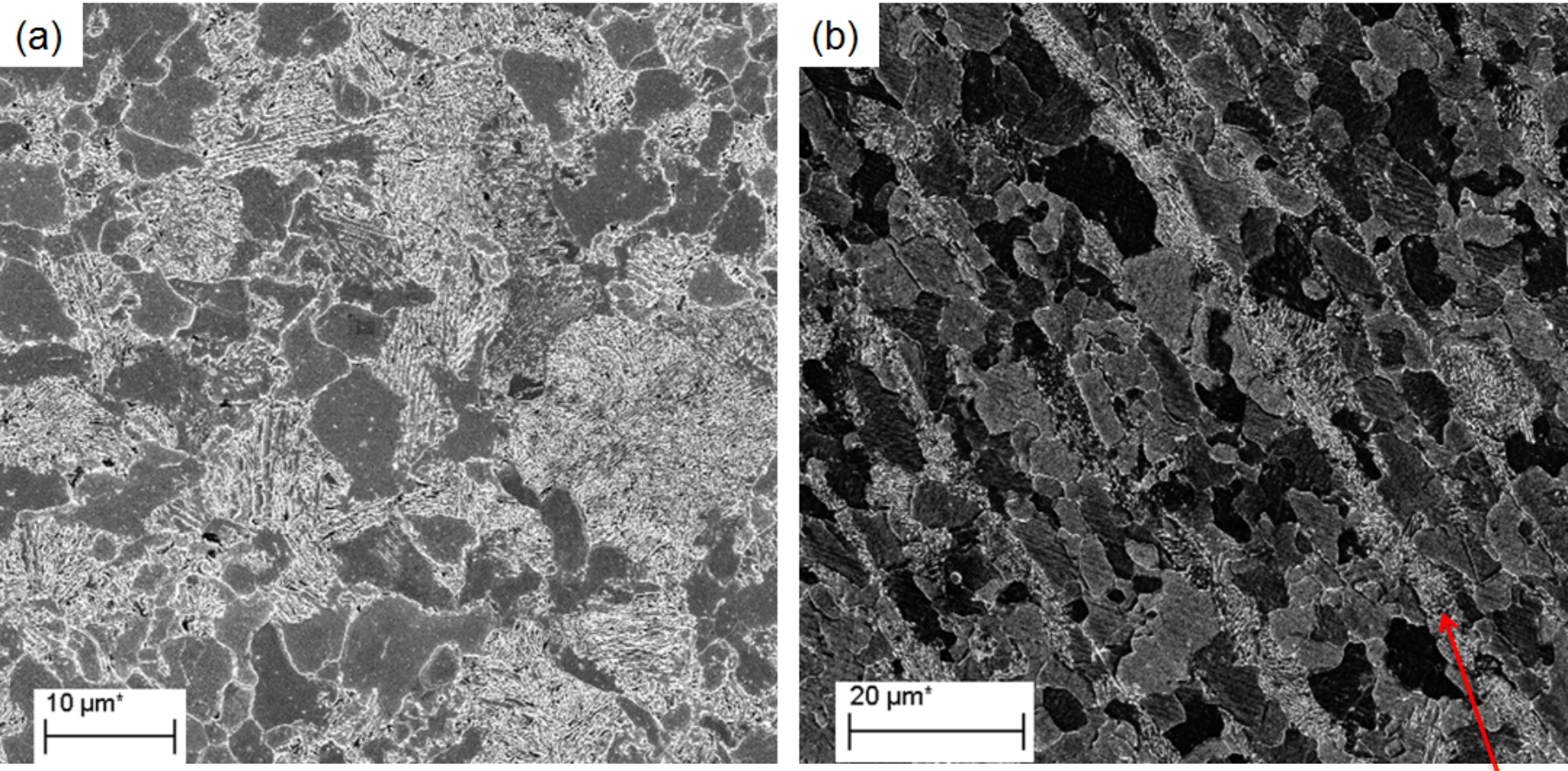
Electropulsing pearlitic steel at ambient condition





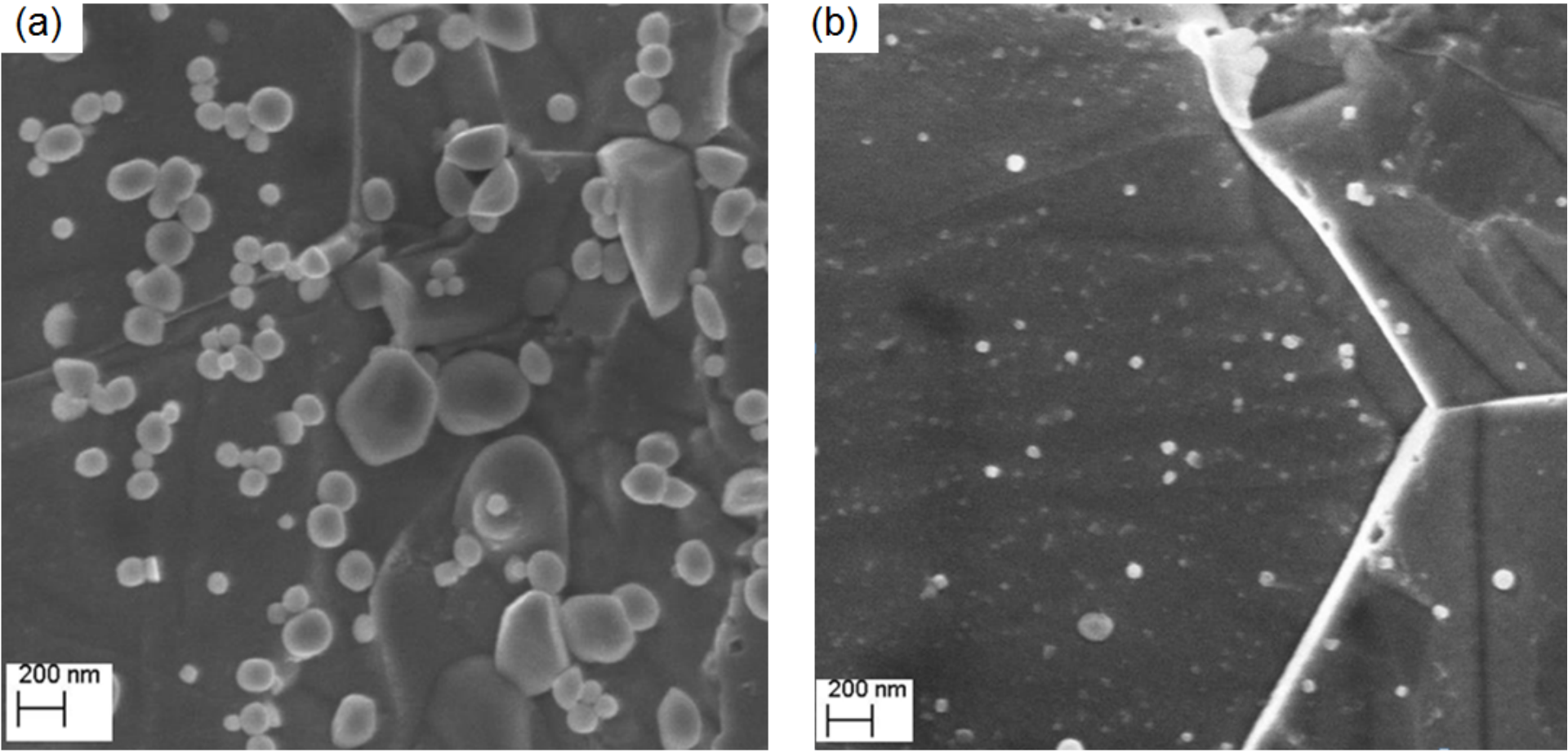
The microstructure of cementite (a) before electropulsing and (b) after electropulsing

Electropulsing TRIP steel at ambient condition



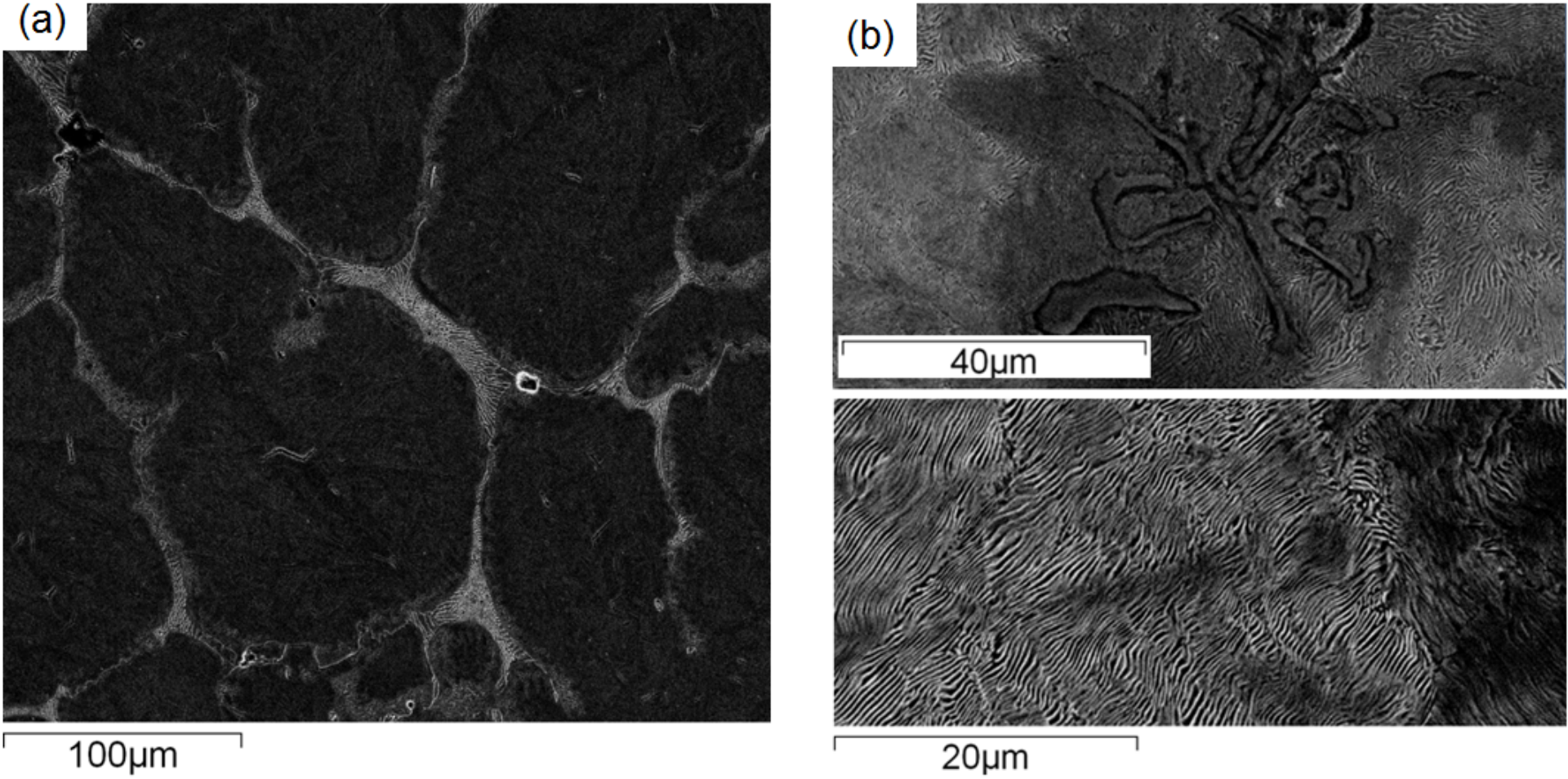
The microstructure of TRIP steel (a) before electropulsing and (b) after electropulsing

Electropulsing stainless steel at elevated temperature



The secondary phase particles (a) without and (b) with the electropulsing during annealing

Electropulsing liquid steel containing inclusions



The inclusions in cast (a) without and (b) with electropulsing treatment

Electropulsing-induced heat effect

Electrical energy per pulse: $Q_e = I^2 R \Delta t$

If all energy converted to heat: $Q_e = mc\Delta T$

This gives temperature rising: $\Delta T = I^2 R \Delta t / (mc)$

where $R = \rho_e L / S$ and $m = \rho_d LS$

One has: $\Delta T = \frac{I^2 \rho_e \Delta t}{S^2 c \rho_d} = \frac{j^2 \rho_e \Delta t}{c \rho_d}$

Electropulsing-induced heat effect is negligible

Materials parameters for 316L stainless steel:

$c = 450\ J/(kg \cdot K)$, $\rho_d = 7.8 \times 10^3\ kg/m^3$, $\rho_e = 9.58 \times 10^{-8}\ \Omega \cdot m$

Electropulse parameters

$j = 6.3 \times 10^8\ A/m^2$, $\Delta t = 20\ \mu s$

Temperature rising due to 1 pulse $\Delta T = \frac{j^2 \rho_e \Delta t}{c \rho_d} = 0.217 K$

Heat rate due to electropulsing (suppose 1 Hz)

$$\dot{\Delta T} = 0.217 K / s$$

Energy consumption in electropulsing

Total work in a single electropulsing $W = I^2 R \Delta t$

Required electric power $P = \frac{W}{t} = I^2 R \Delta t \cdot f$

pulse frequency

Substituting following parameters

Electropulsing parameters

j = 6.3×10^8 A/m^2, Δt = 20 μs, f=1 Hz

Sample parameters

$\rho_e = 9.58 \times 10^{-8}$ Ω·m, L=10 cm, S = 4 mm^2

The consumed electric power in electropulsing processing

$P = 0.304 Watts$

Thermodynamic effect of electropulsing

Total free energy change in structural transformation

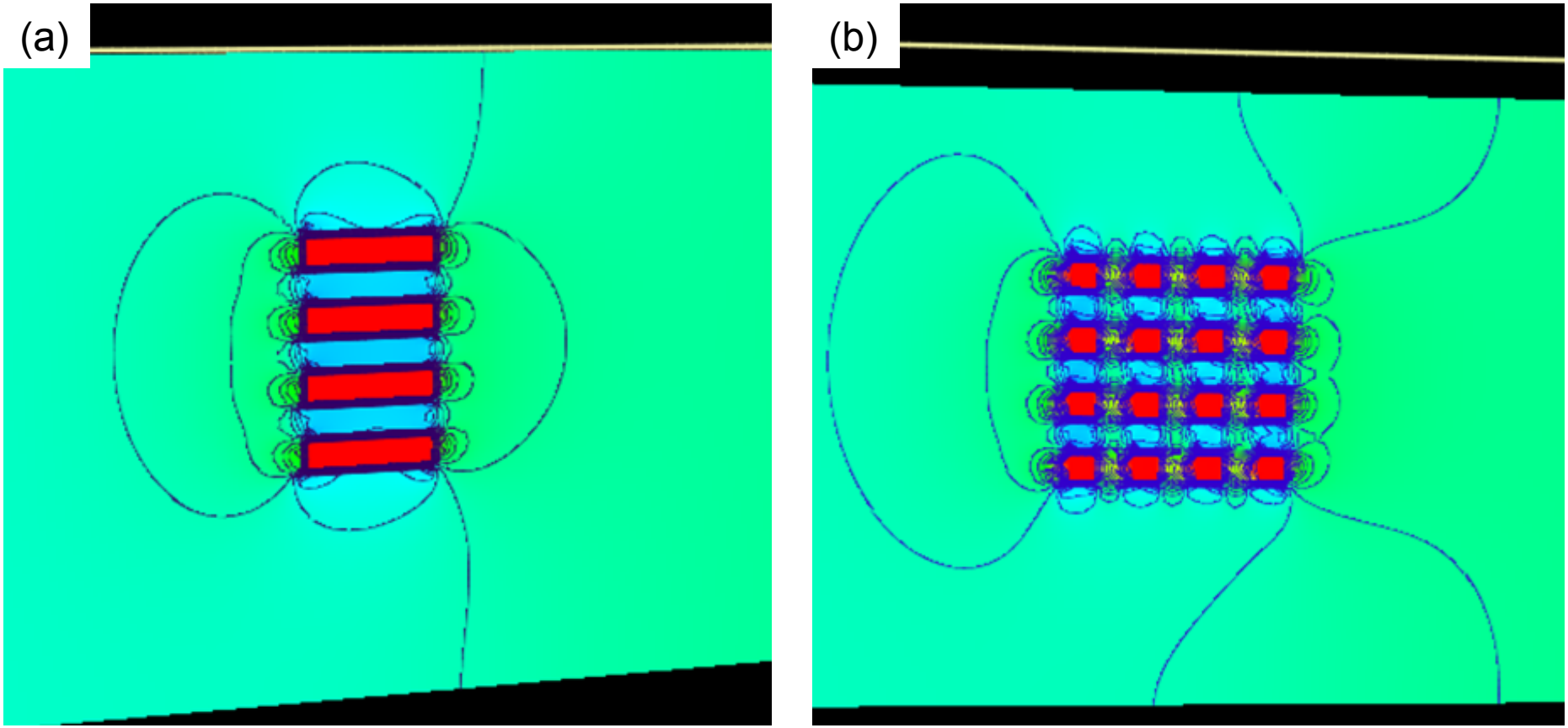
$$\Delta G = \Delta G_{chem} + \Delta G_{surf} + \Delta G_{elec}$$

The electropulsing associated free energy change

$$\Delta G_{elec} = \frac{\mu}{8\pi} \int \int \frac{\vec{j}_b(r) \cdot \vec{j}_b(r') - \vec{j}_a(r) \cdot \vec{j}_a(r')}{|r - r'|} dr dr'$$

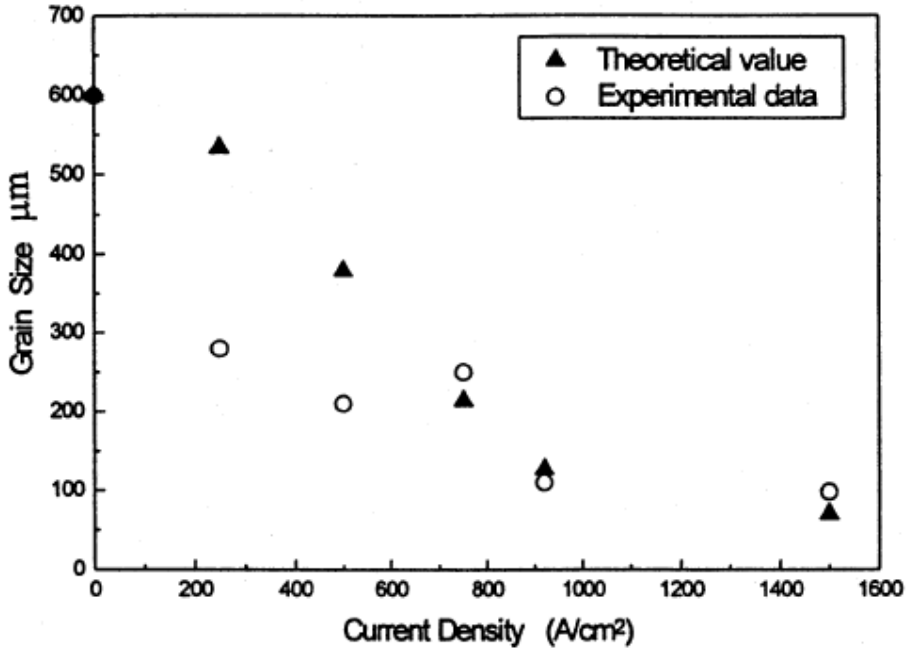
where μ is the magnetic permeability. $\vec{j}_b(r)$ and $\vec{j}_a(r)$ are current density distributions before and after the microstructural transformation, respectively. r and r' are two different positions inside the sample.

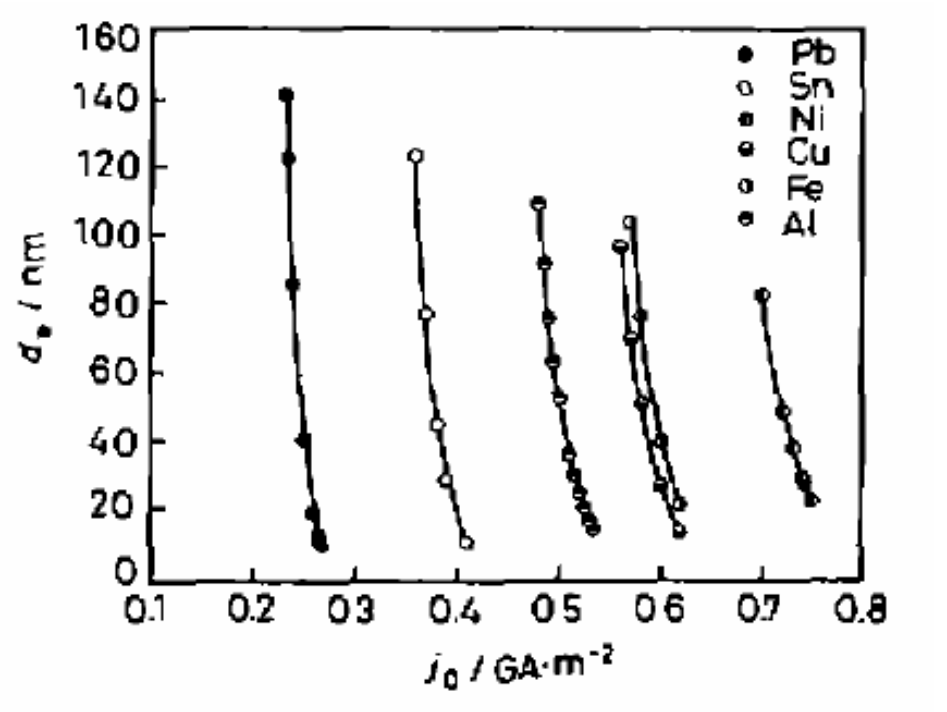
Computation of electrical current distribution



Current distribution (a) before and (b) after cementite fragmentation

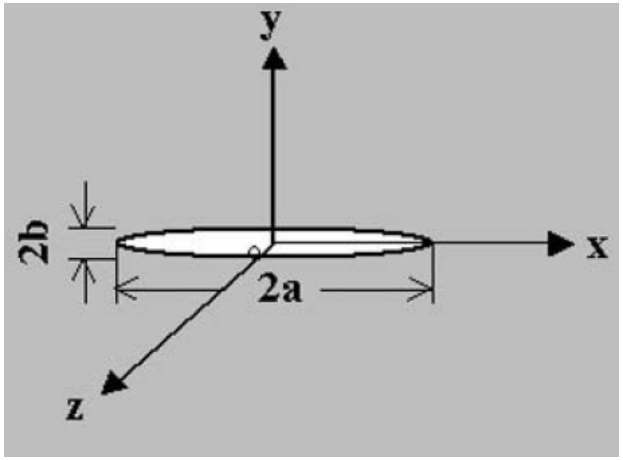
Calculation of electropulse-induced grain refinement



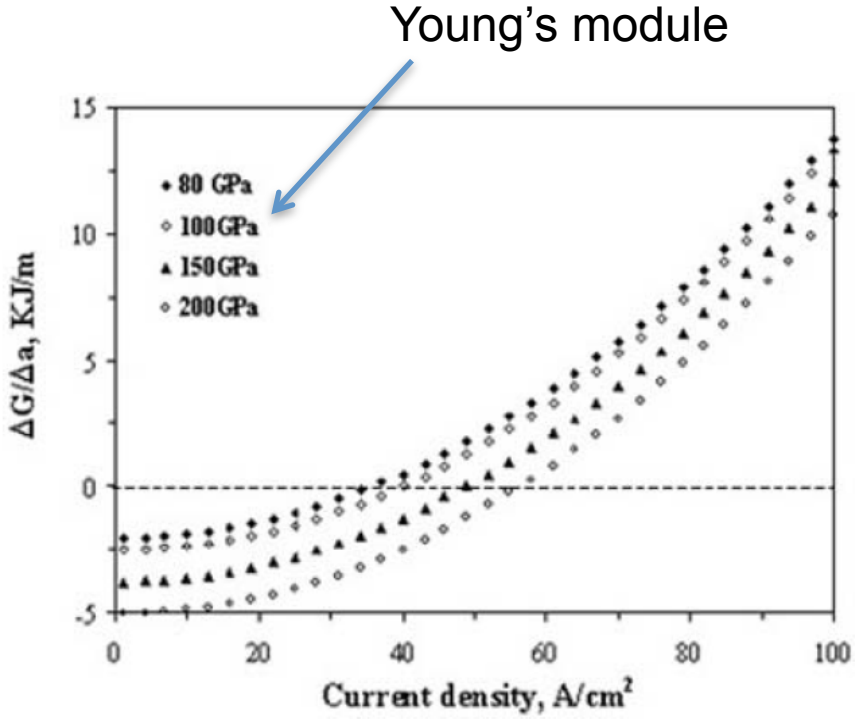


(a) Validation against experiments and (b) further predictions

Calculation of electropulse-induced crack healing



$$\Delta W_e = \frac{\pi \mu j_0^2 (c+d)^4}{64} \cdot \frac{\Delta a}{a}$$



Numerical results show the strong enough electropulsing effect on solid materials

Conclusions

- Electropulsing consumes negligible energy and has negligible thermal effect.
- Electropulsing produces significant effect at ambient and elevated temperature.
- It is still early stage in understanding the electropulsing processing technology