# Misorientation within Coalesced Bainite

POSTECH GIFT Graduate Institute of Ferrous Technology

Computational Metallurgy Laboratory

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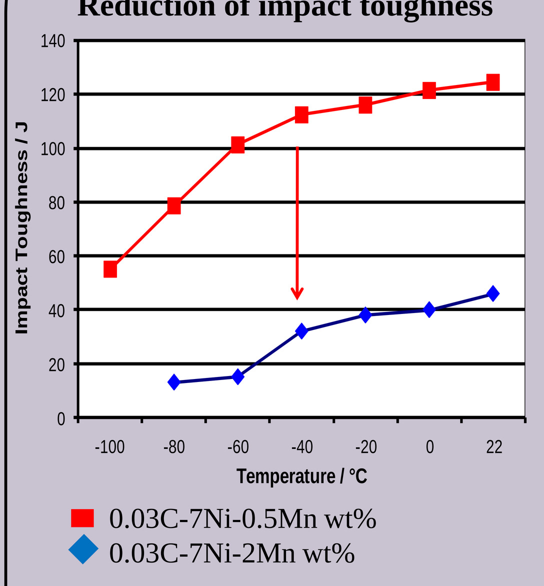
**Abstract**

Coarse crystals of bainite can form by the coalescence of thin, individual platelets of bainite under appropriate circumstances. Although these coarse grains are essentially single–crystals, there exist significant orientation gradients across their dimensions. It is demonstrated that these gradients arise because of the plasticity induced in the austenite due to the transformation strain associated with bainite growth. The resulting localized change in austenite orientation is then inherited by new bainite growth which consumes the deformed austenite.

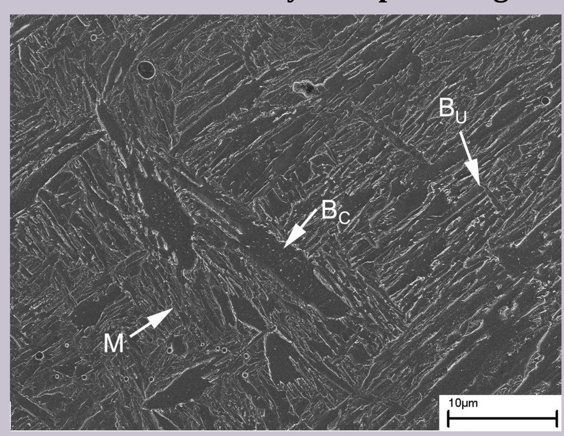
*Keywords*: bainite, plastic strain, coalescence

## 1. Introduction

**Reduction of impact toughness**

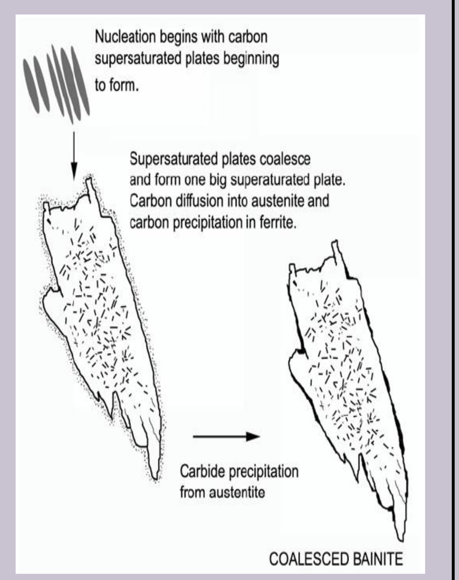



**Microstructure of alloy with poor toughness**




$B_C$ : Coalesced bainite
$B_U$ : Upper bainite
M : Martensite

**The formation mechanism**




✓ It was reported that the existence of coalesced bainite caused the huge reduction of impact toughness in weld metal (Keehan *et al.*, 2006).
✓All that required to form coalesced bainite is identically oriented platelets (Bhadeshia *et al., 2006).*

**It is important to know the orientation evolution of bainite platelets.**

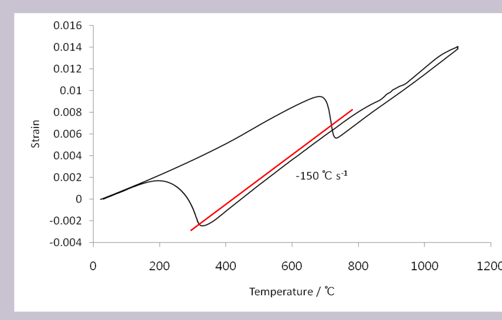
## 2. Experiment and results

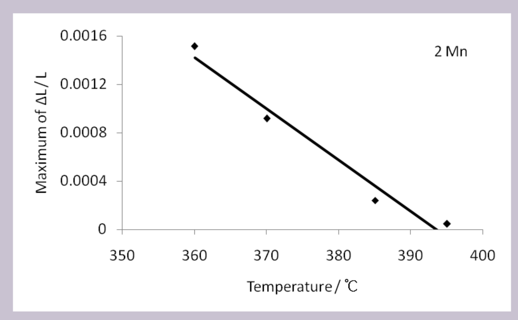
**Composition of alloy (wt%)**

| C | Si | Mn | P | S | Cr | Ni | Mo | W |
|---|---|---|---|---|---|---|---|---|
| 0.03 | 0.23 | 2.05 | 0.01 | 0.008 | 0.43 | 7.1 | 0.63 | 0.004 |
| Co | V | Nb | Cu | Al | Ti | B | O | N |
| 0.008 | 0.021 | 0.004 | 0.02 | 0.001 | 0.011 | 0.0012 | 0.031 | 0.011 |

✓The alloy with more coalescence was selected.

**Martensite-start ($M_S$) and bainite-start ($B_S$) temperature**

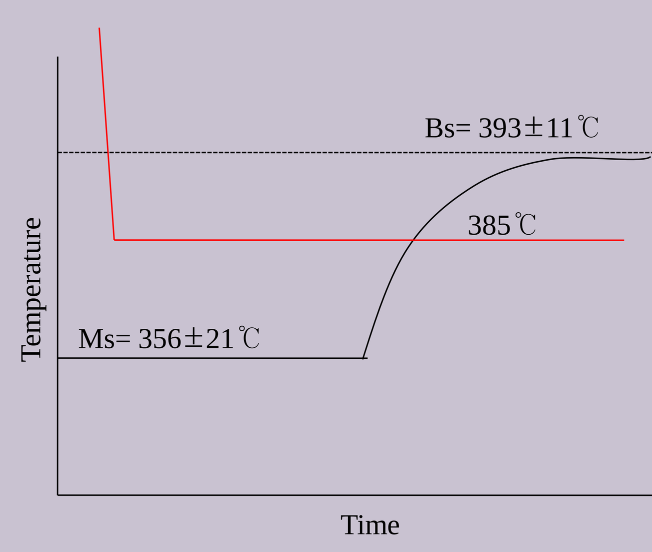



✓ The temperature where the martensite with 0.1% volume fraction was formed was measured as $M_S$ (Yang *et.al.*, 2007).

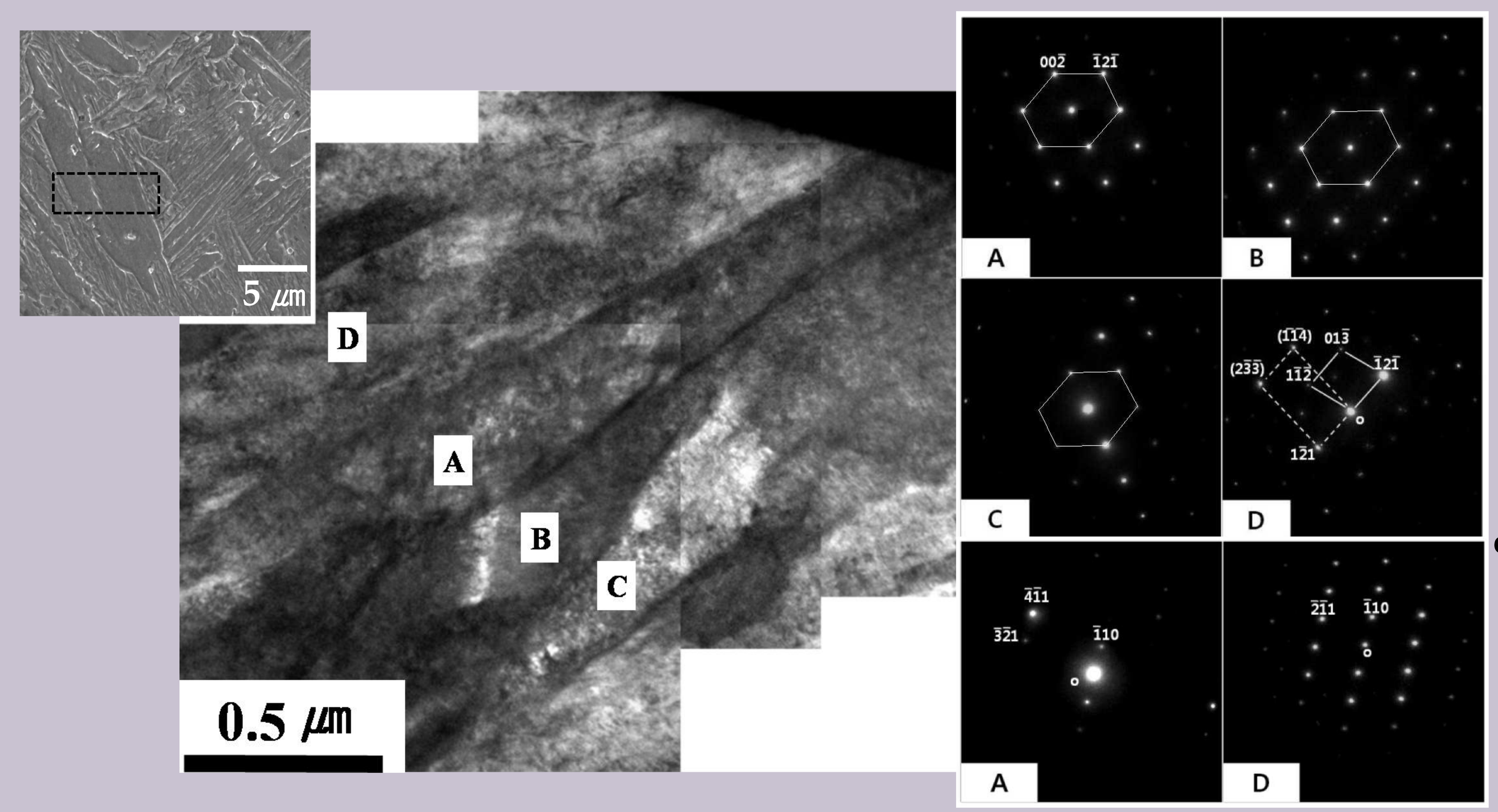
✓ It was assumed that maximum length change by bainite transformation is proportional to the bainite fraction.

**Isothermal heat treatment for bainite transformation**




✓ Isothermal transformation was carried on between $M_S$ and $B_S$ to avoid the possibility of confusion with autotempered martensite.

### TEM analysis




| Misorientation relation between A and D | |
|---|---|
| Axis | Angle |
| < $\bar{1}2\bar{1}$ > | 10.7 ° |
| | 6.1 ° |
| < $\bar{1}10$ > | 9.4 ° |

Crystallographically very close to the diad symmetry

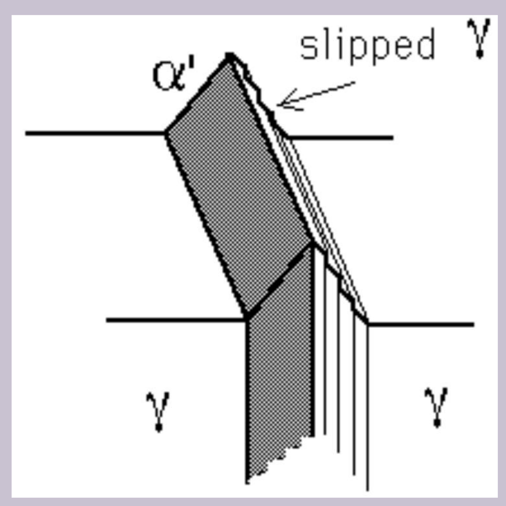
✓ The cross sectional area of coalesced bainite was obtained using FIB technique.

✓ It was confirmed that there exist internal boundaries between individual platelets inside coalesced bainite.

✓ The misorientation between adjacent platelets was estimated to be very small closed to the diad symmetry.

## 3. Discussion

**Plastic relaxation in austenite**



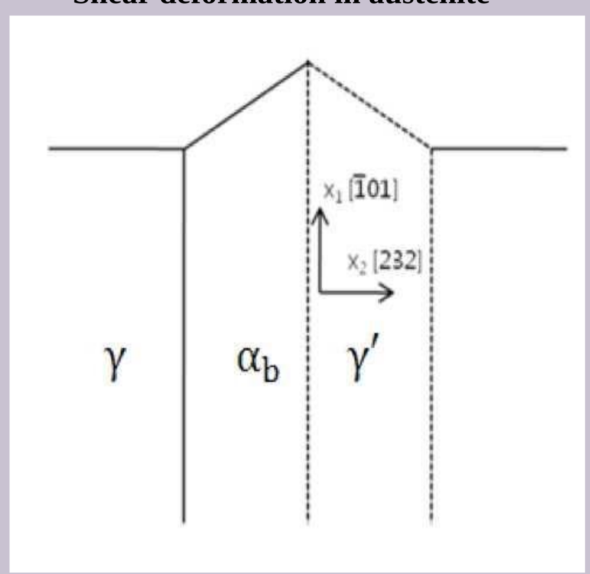

**Empirical equation for displacive transformation products**

$$\log \rho_d = 9.28480 + \frac{6880}{T} - \frac{1780360}{T^2}$$

$\rho_d$ =4.25 x $10^{15}$ $m^{-2}$ at T= 385 ℃

✓ The growth of bainite is accommodated plastically in adjacent austenite, which leads to the generation of dislocations.
✓ Since the bainite transformation involves the conservative motion of interface, those dislocations are inherited to next bainite platelet (Bhadeshia, 2002).
✓ Empirical equation was used to estimate the dislocation density (Takahashi and Bhadeshia, 1990).

**Shear deformation in austenite**



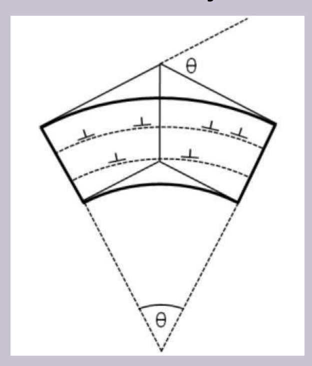

**Activated slip systems in austenite**

$a_2$ {111}<$\bar{1}$01> and - $d_2$ {1$\bar{1}$1}<10$\bar{1}$>

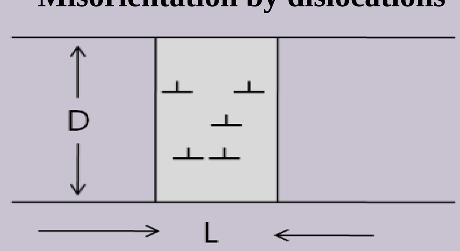
$$\frac{\rho_{a_2}}{\rho_{-d_2}} = 5$$

✓ The volume expansion during transformation was ignored (simple shear deformation was assumed).
✓ The habit plane and growth direction are assumed to be $(232)_\gamma$ and $[\bar{1}01]_\gamma$, respectively (Davenport, 1974).
✓ Given the deformation, the activated slip systems were obtained using Taylor theory (Lee, 2006).

**Lattice rotation by excess dislocations**




**Misorientation by dislocations**




$$\theta = \frac{b}{d} = b\rho L$$

✓ Slip dislocations causes the rotation of crystal about the axis normal to slip direction and the normal direction of slip plane (Nye, 1953).
✓ The misorientation across the dislocation distributed area can be calculated. Typical width of bainite plate, 0.2 ㎛ was selected for L.
✓ Combined rotation by dislocations of different slip systems gives total misorientation.

## 4. Calculation

**Resultant misorientation by excess dislocations**

| $\phi$ | $R_a R_b$ | $\frac{1}{2}R_a \frac{1}{2}R_b \frac{1}{2}R_a \frac{1}{2}R_b$ | $\frac{1}{2}R_b \frac{1}{2}R_a \frac{1}{2}R_b \frac{1}{2}R_a$ | $R_b R_a$ |
|---|---|---|---|---|
| 0.25 | 2.43° $[\overline{0.518}\,0.686\,\overline{0.511}]$ | 2.43° $[\overline{0.516}\,0.686\,\overline{0.513}]$ | 2.43° $[\overline{0.513}\,0.686\,\overline{0.516}]$ | 2.43° $[\overline{0.511}\,0.686\,\overline{0.518}]$ |
| 0.50 | 4.86° $[\overline{0.521}\,0.686\,\overline{0.508}]$ | 4.86° $[\overline{0.518}\,0.686\,\overline{0.511}]$ | 4.86° $[\overline{0.511}\,0.686\,\overline{0.518}]$ | 4.86° $[\overline{0.508}\,0.686\,\overline{0.521}]$ |
| 0.76 | 7.28° $[\overline{0.524}\,0.686\,\overline{0.505}]$ | 7.28° $[\overline{0.519}\,0.686\,\overline{0.510}]$ | 7.28° $[\overline{0.510}\,0.686\,\overline{0.519}]$ | 7.28° $[\overline{0.505}\,0.686\,\overline{0.524}]$ |

✓ The density of excess dislocation was estimated by giving the fraction, $\phi$ to total dislocation density calculated before.

✓ Four combinations considering the rotation order were selected for calculation.

✓ The direct comparison with the measured one above was limited since there was no information about the actual axis of rotation.

✓ Complete comparison also requires the information about the habit plane and shape deformation.

## 5. Summary

✓ The large plates formed by coalescence of individual bainite platelets retain vestiges of their origin which is visible in TEM image because the plates are not precisely identically oriented in space but relatively misoriented.
✓ The misorientation is explained as crystal rotation by the excess dislocations in austenite adjacent to bainite platelets, which are resulted from plastic accommodation of austenite during bainite transformation.
✓An estimate of the degree of resulting rotation gives reasonable values although it has not been possible to attain a quantitative comparison with experimental observations.
✓ The complete closure with theory requires the three-dimensional crystallography (habit plane, shape deformation and orientation relationship) to be characterized.