Architectured Steel

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THE UNIVERSITY OF TOKYO

DESIGN
OF
FOR
WITH
MATERIALS

Development of Steels

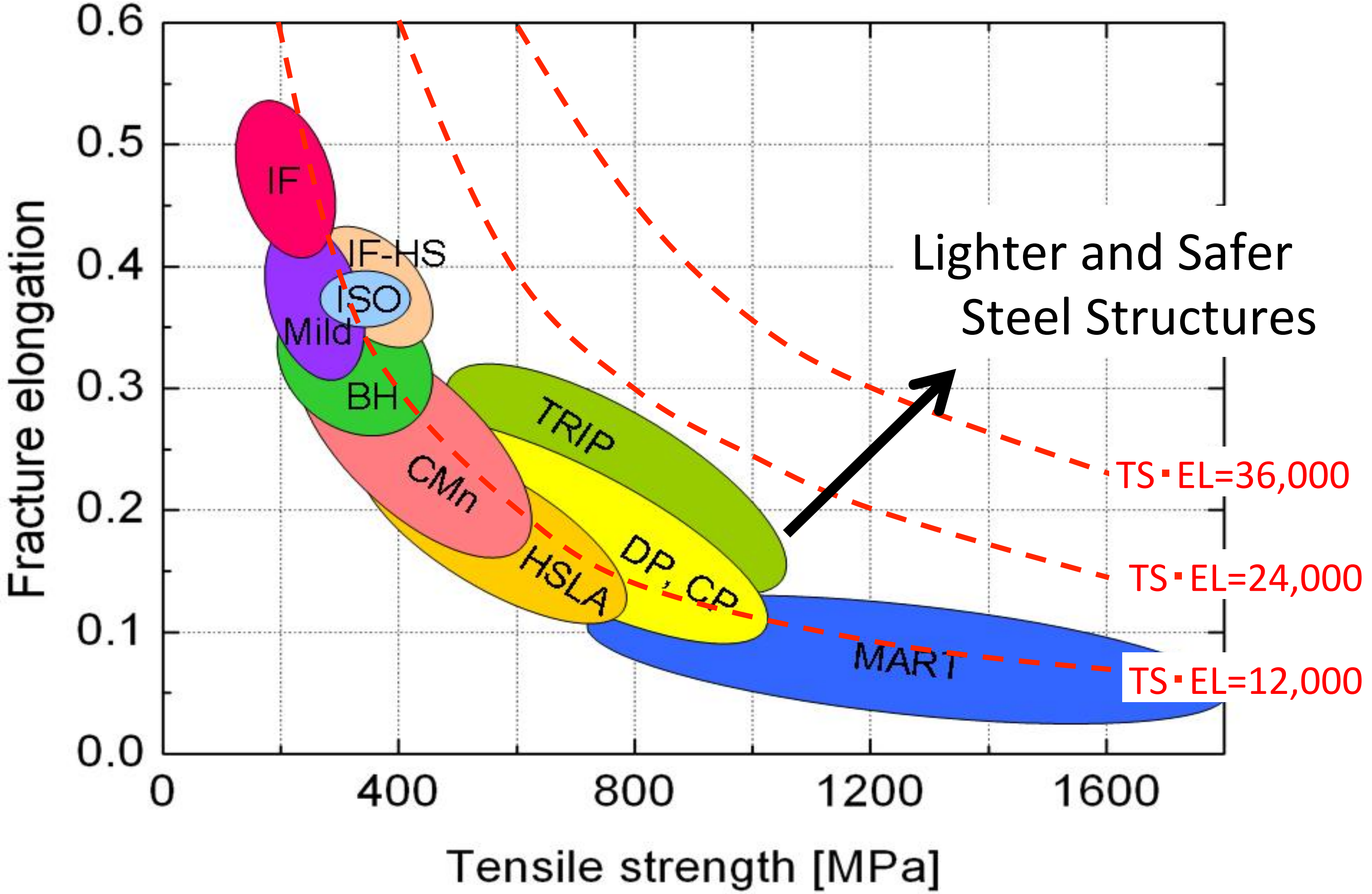
Advances of steels over the last century have been achieved by:

- Fully developed theoretical basis
- Alloy designs with various rare metals
- Microstructure control and refinement through thermo-mechanical control
- High-level purification and homogeneity
- Full use of strengthening mechanisms

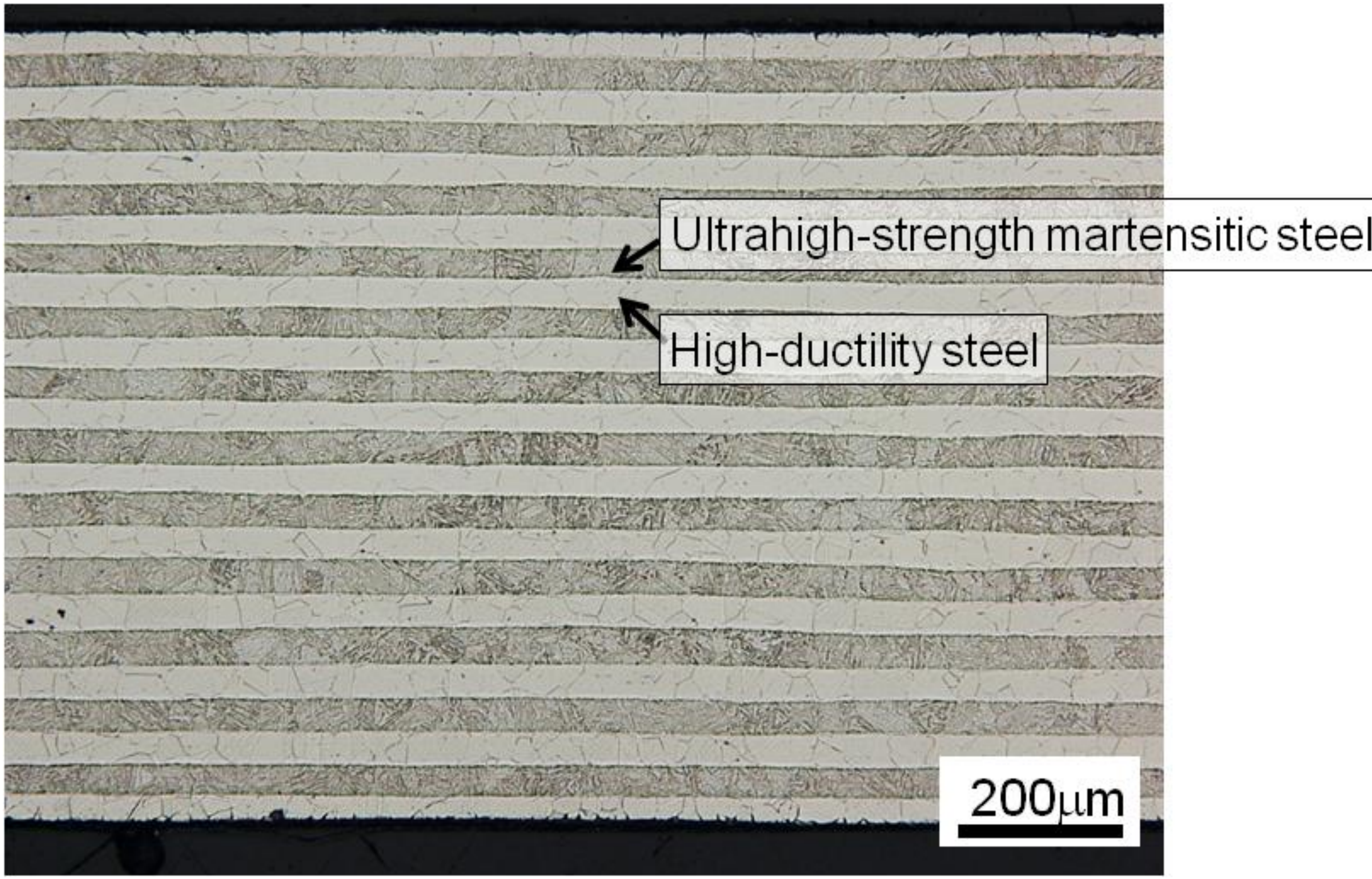
Steels in Future

- Need to meet never-ending demands for higher performance and environment-friendliness
- May need new alloy design, micro- and nano-structure control, and ultimate refinement
- May need an externally architected steel to get away from monolithic steel and from thermodynamically restricted design of steel

Steels for Automobiles



Multilayer Steel Composite



Combination of steels of interest

Process

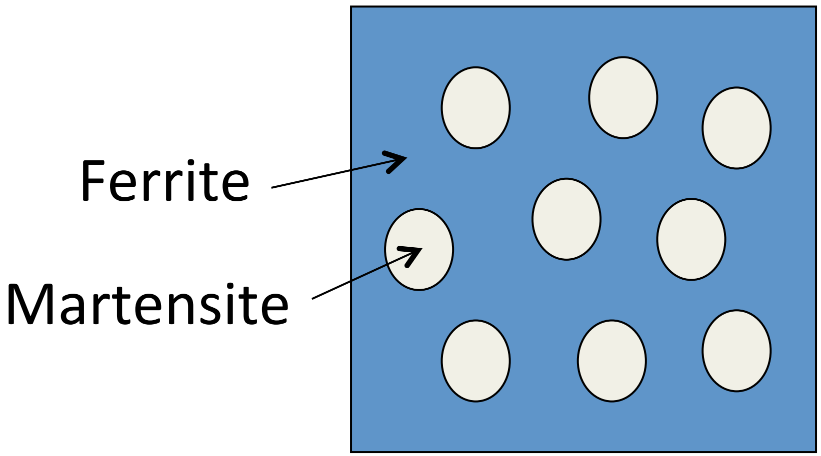
Stacking of Steel Plates → Hot, Warm, or Cold Bond Rolling → Cold Rolling to Sheet → Heat Treatment

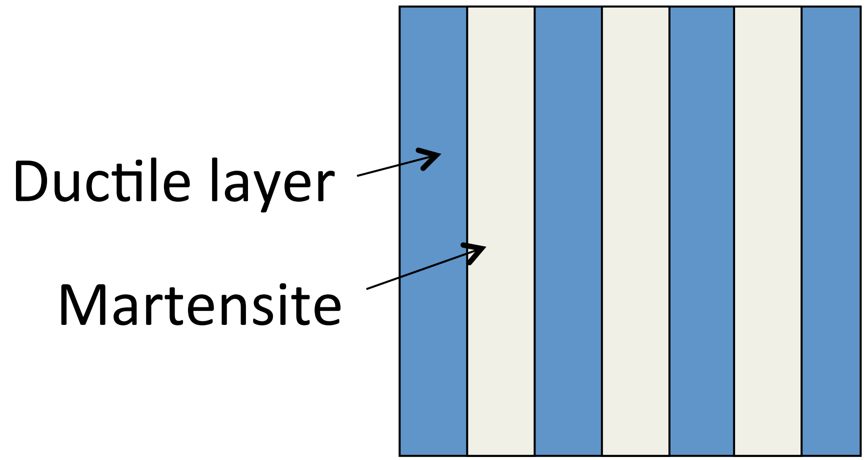
Martensite/Austenite
Martensite/Ferrite
Martensite/TRIP

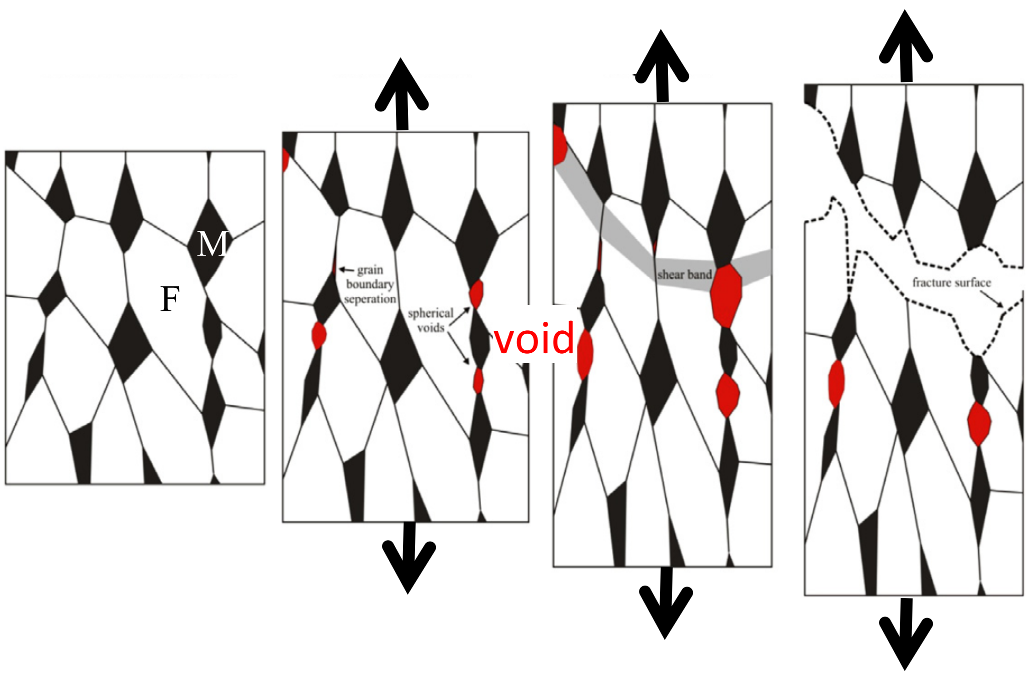
3 to 25 layers with/without thin Ni layers to prevent carbon diffusion

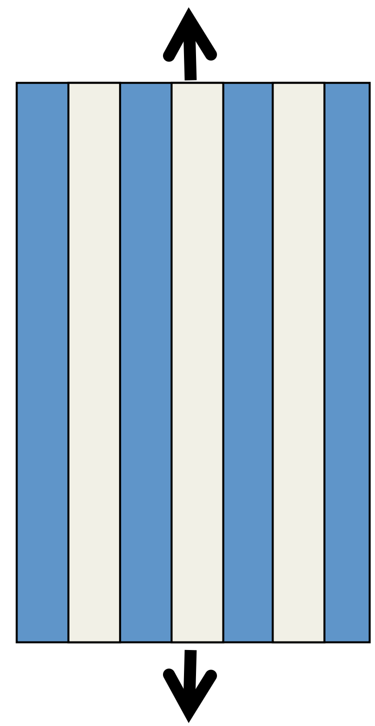
Quenching
(No tempering)

Concept for High-ductility Martensite



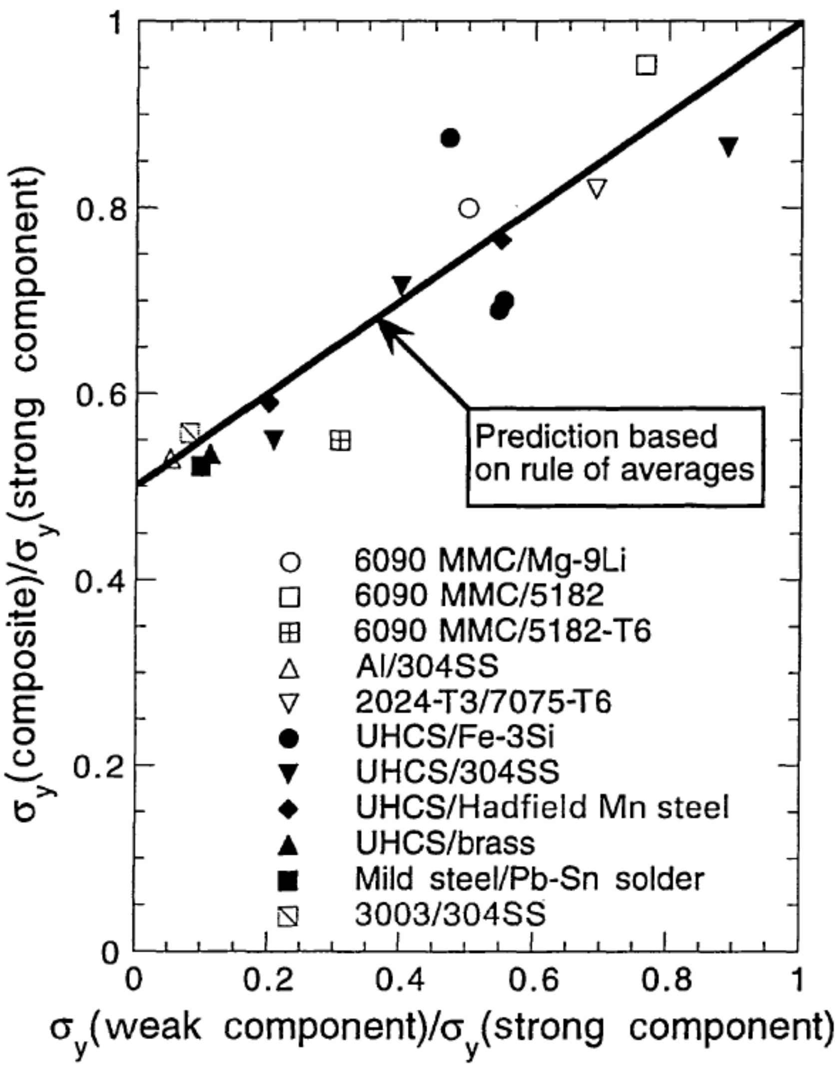




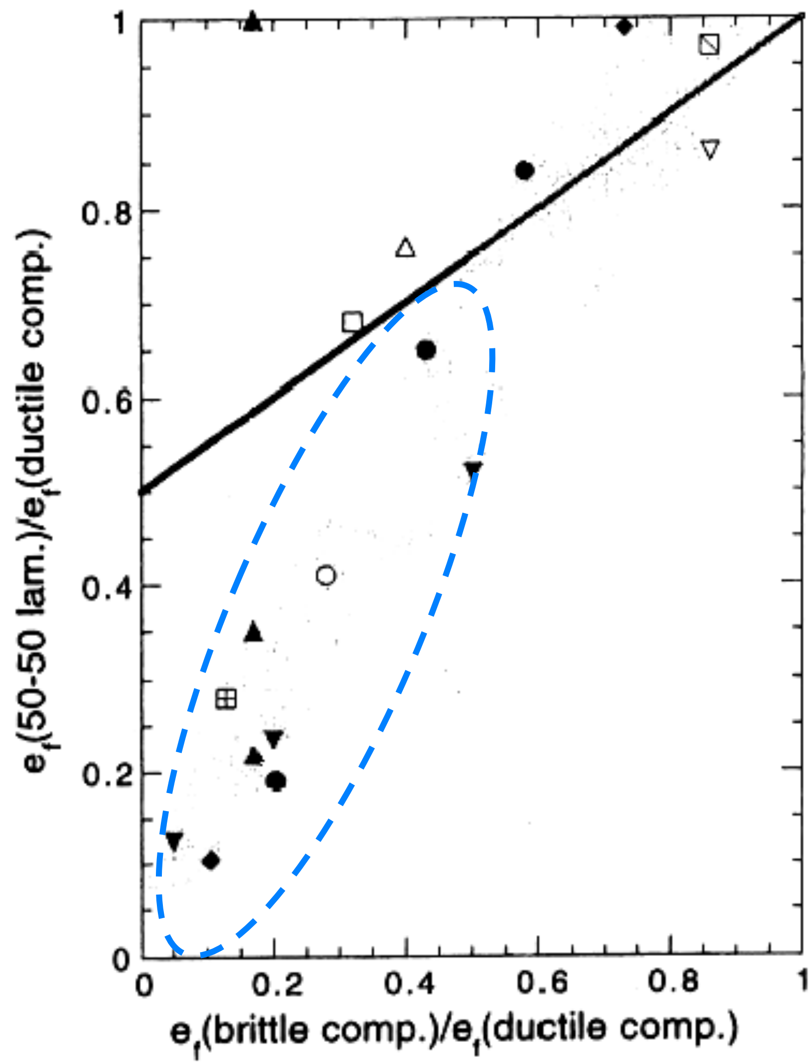


*J. Kadkhodapour et al., Acta Mater. 59 (2011) 2575–2588

Strength



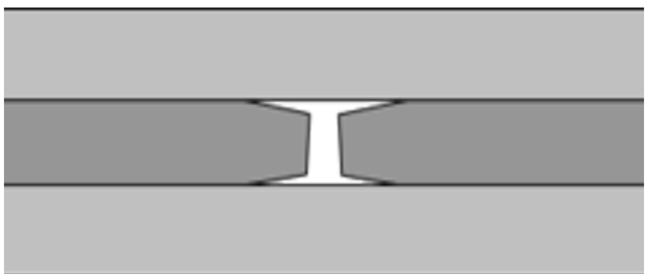
Ductility

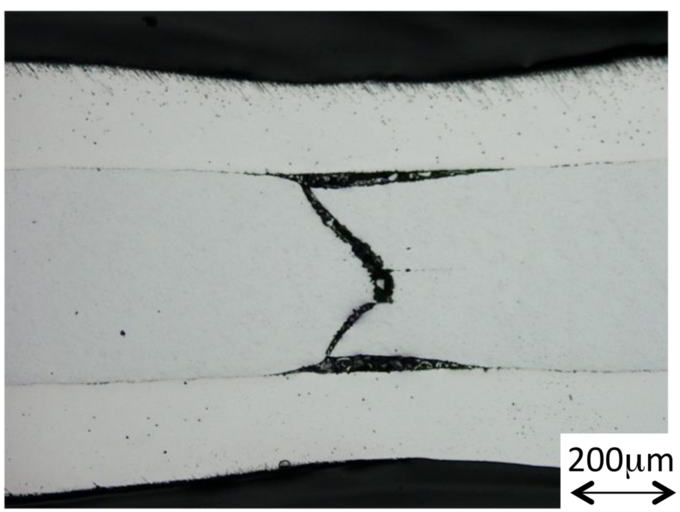


Lesuer et al. Int. Mater. Rev. (1996)

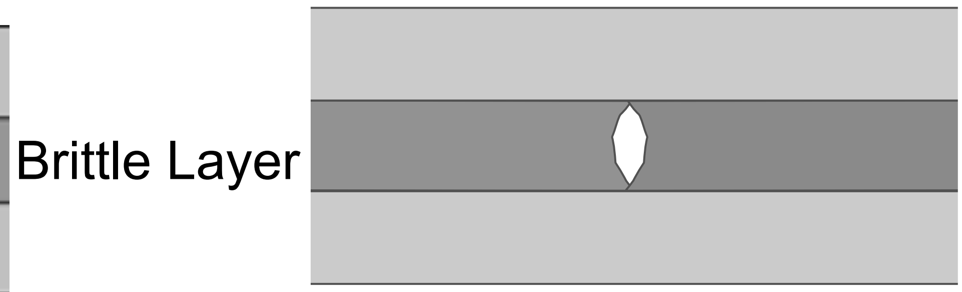
Factors lowering Elongation

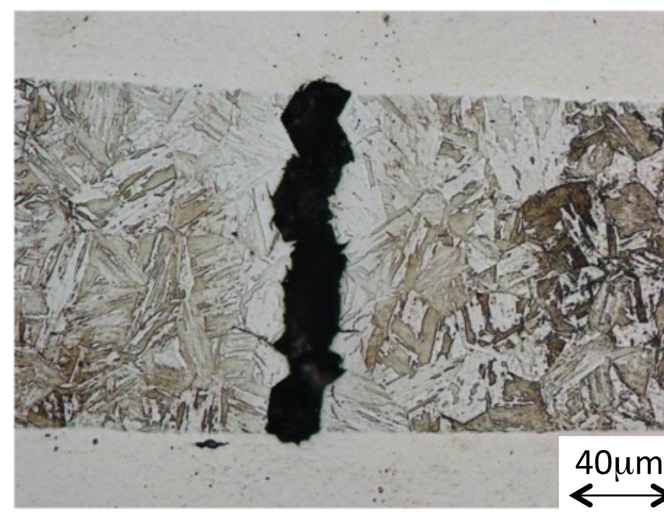
Delamination H-shape Crack



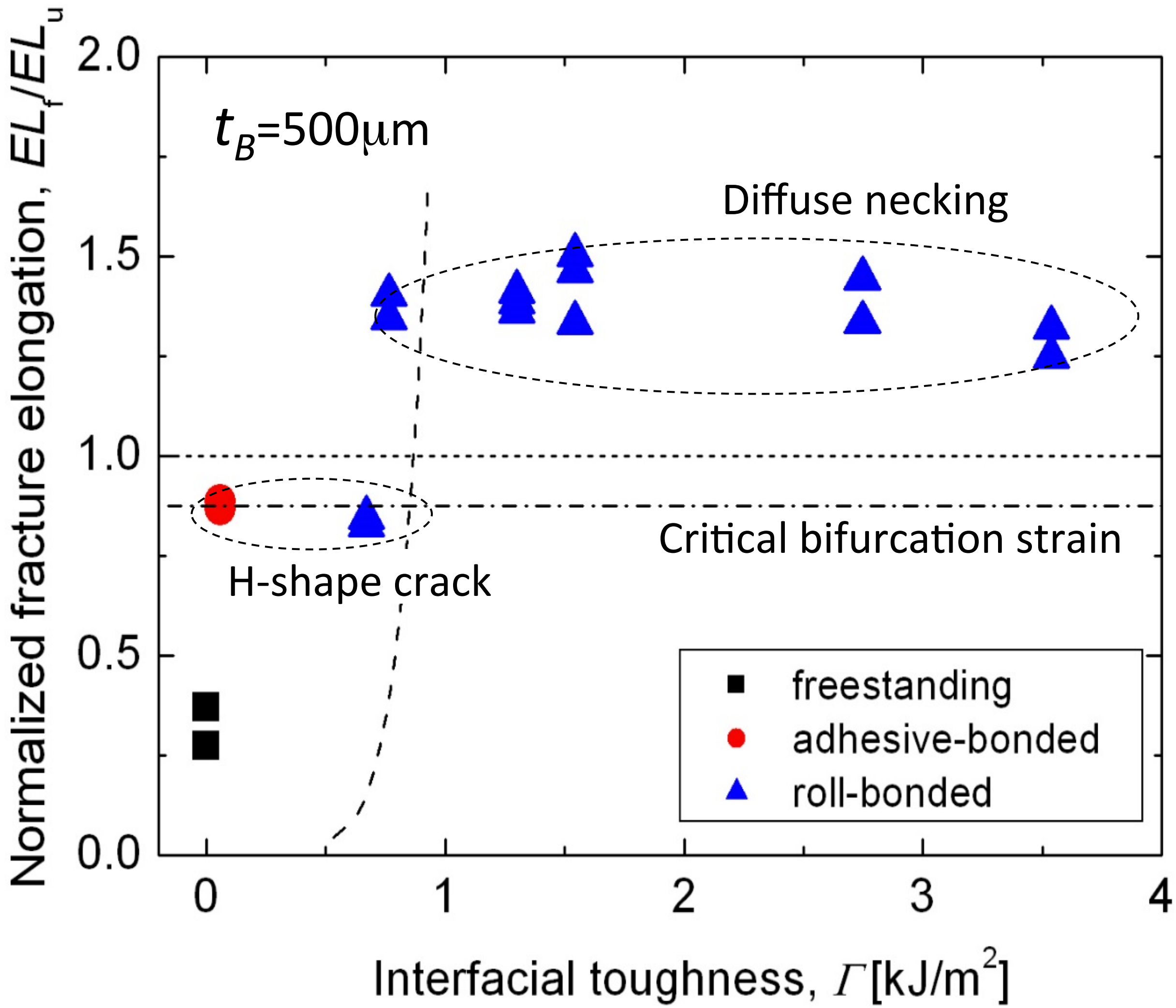


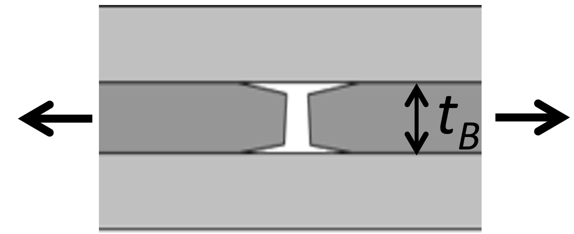
Tunnel Crack





Prevention of H-shape Crack



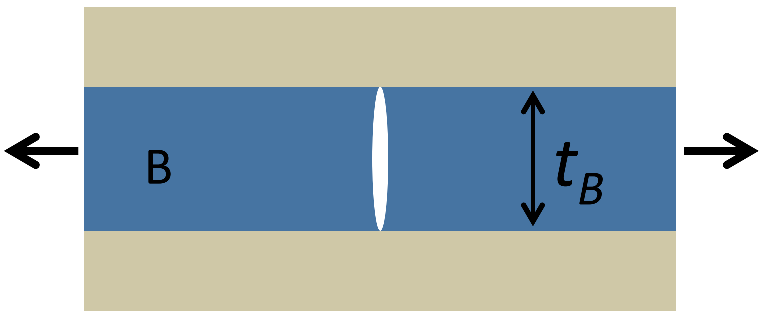


$$\Gamma_{int} \geq 0.26 \frac{\pi t_B \sigma^2}{2E_B}$$

Suiler (2004)

Prevention of Tunnel Crack

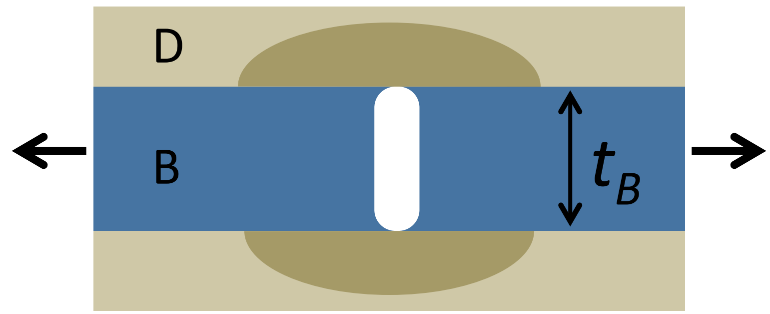
Elastic



$$t_B \le \frac{4K_{IC}^2}{\pi\sigma^2}$$

(Suo 1990)

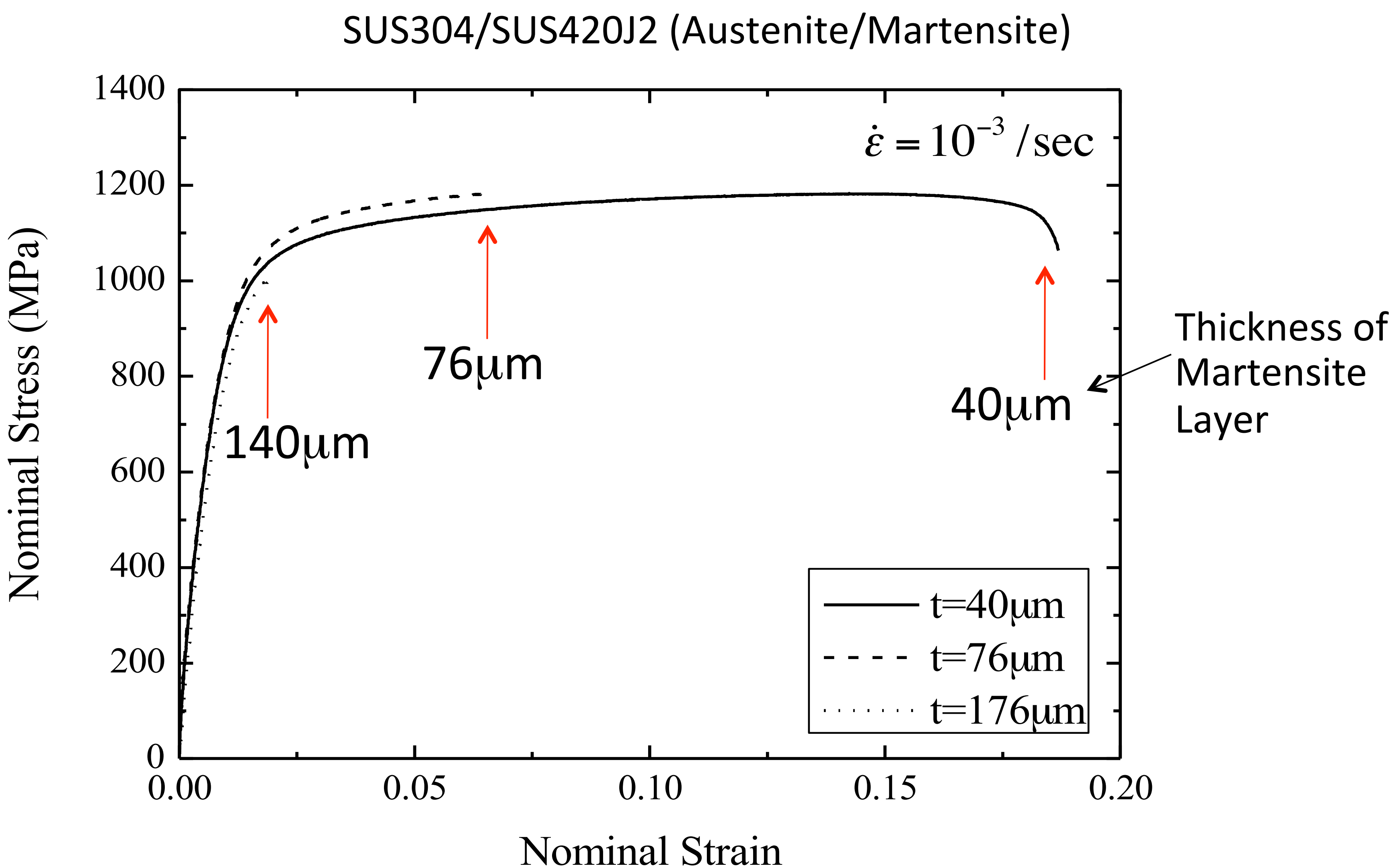
Elasto-plastic



$$t_B \le \frac{2\sqrt{3}K_{IC}^2\sigma_{Y,D}}{\sigma^3}$$

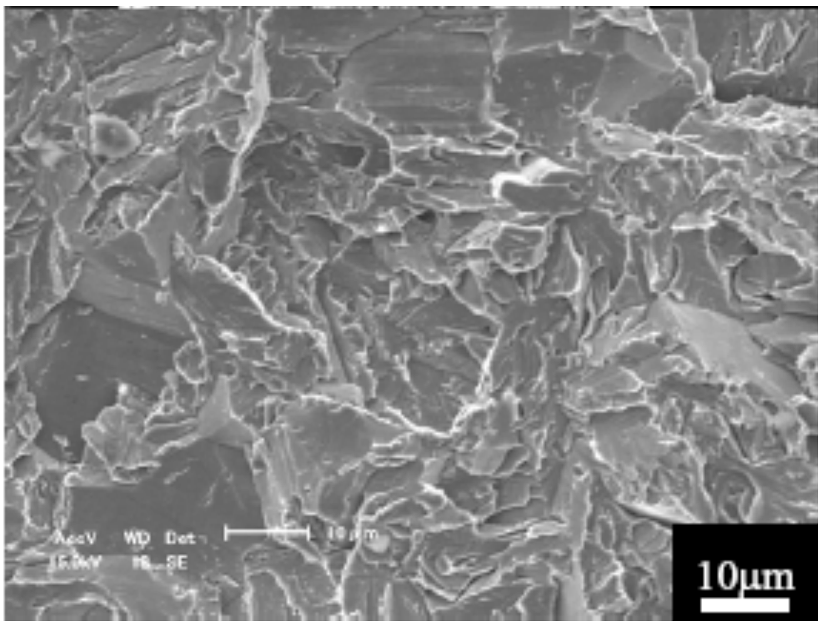
(this study)

Effect of Thickness of Brittle Layer



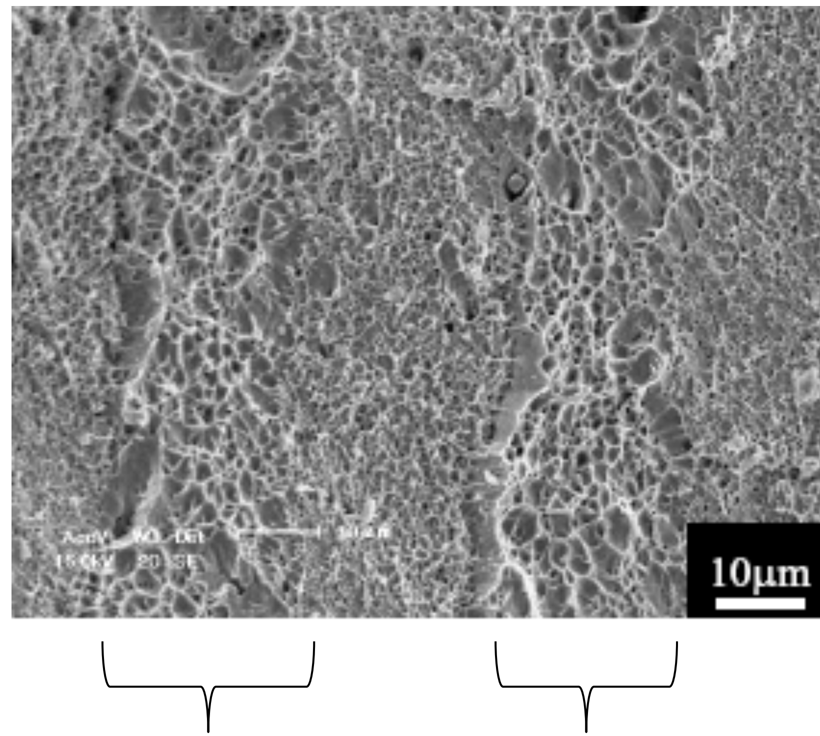
Effect of Thickness of Brittle Layer

$t_{martensite\ layer}$=140μm



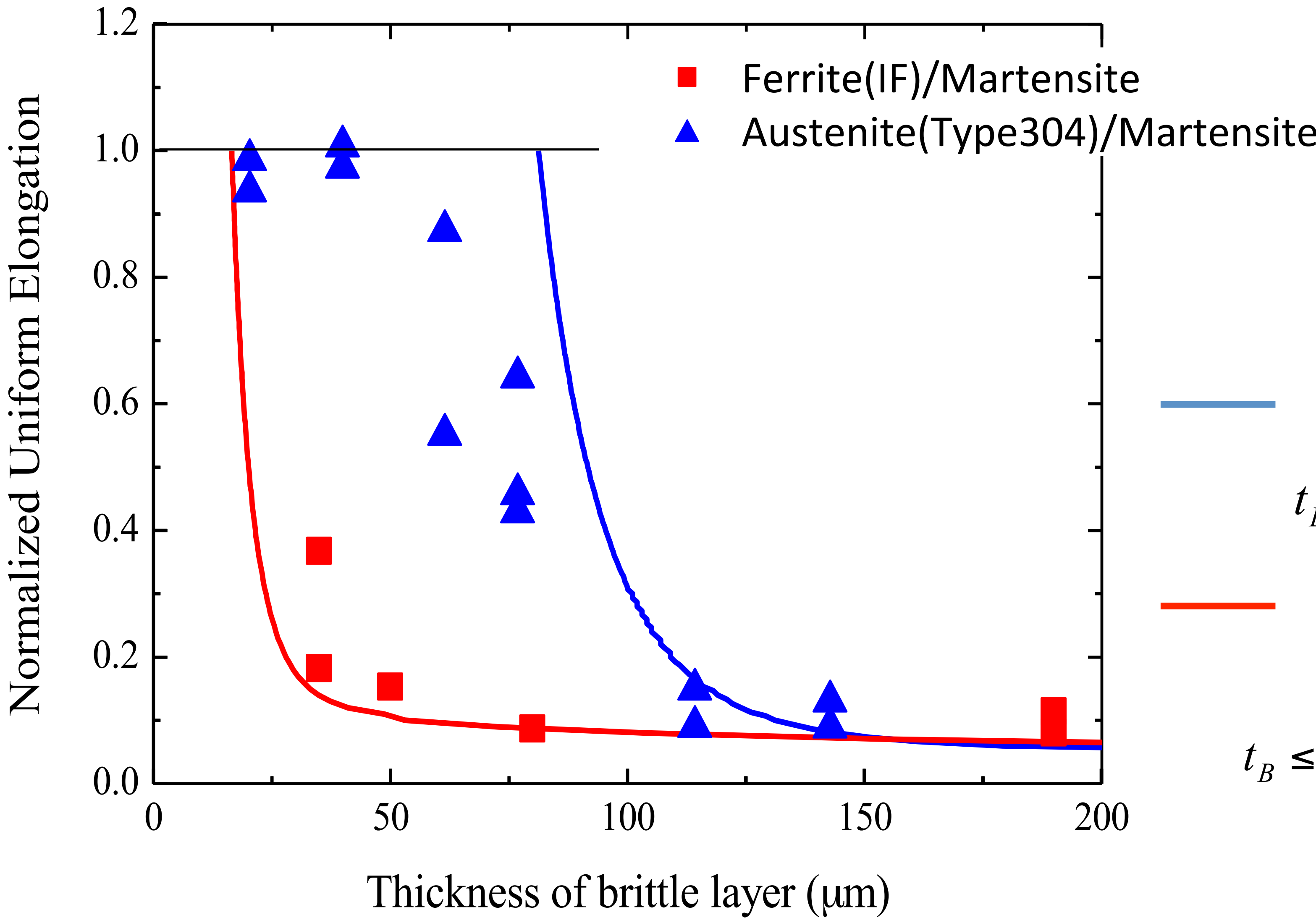
martensite

$t_{martensite\ layer}$=40μm



martensite martensite

Effect of Ductile Layer on Elongation



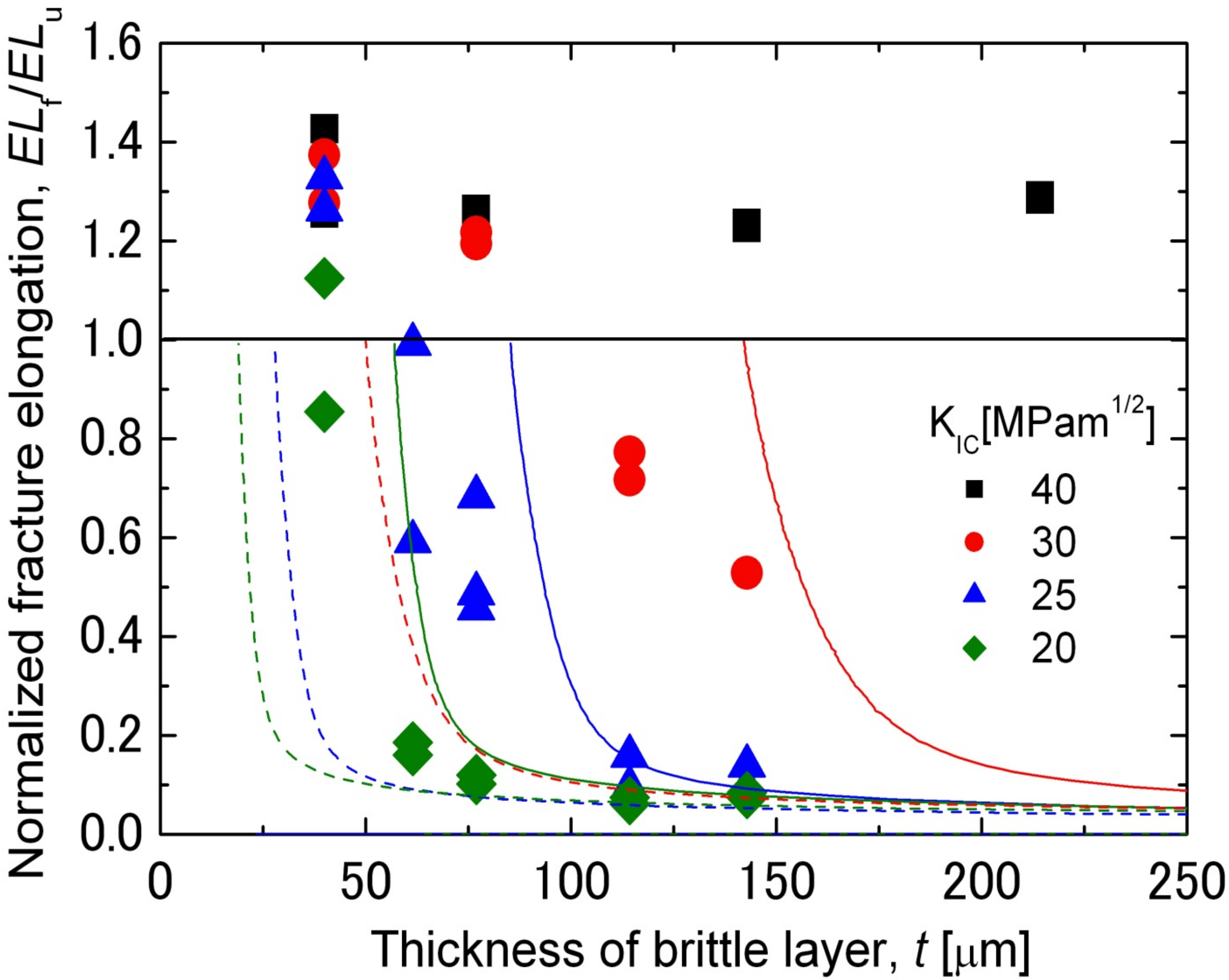
Elastic

$$t_B \leq \frac{4K_{IC}^2}{\pi\sigma^2}$$

Elasto-plastic

$$t_B \leq \frac{2\sqrt{3}K_{IC}^2\sigma_Y}{\sigma^3}$$

Effect of K_{IC} of Brittle Layer on Elongation



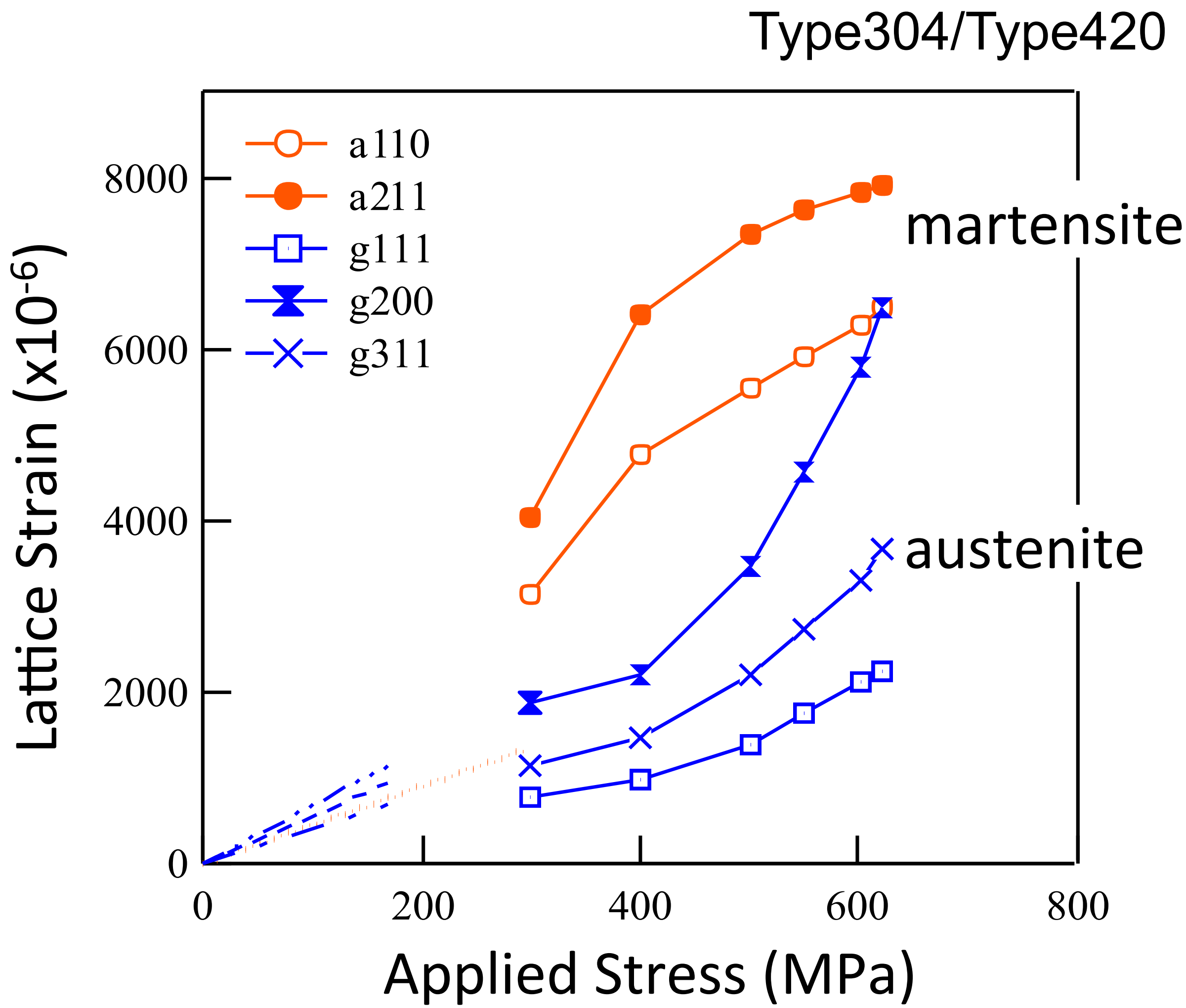
Elastic

$$t_B \leq \frac{4K_{IC}^2}{\pi\sigma^2}$$

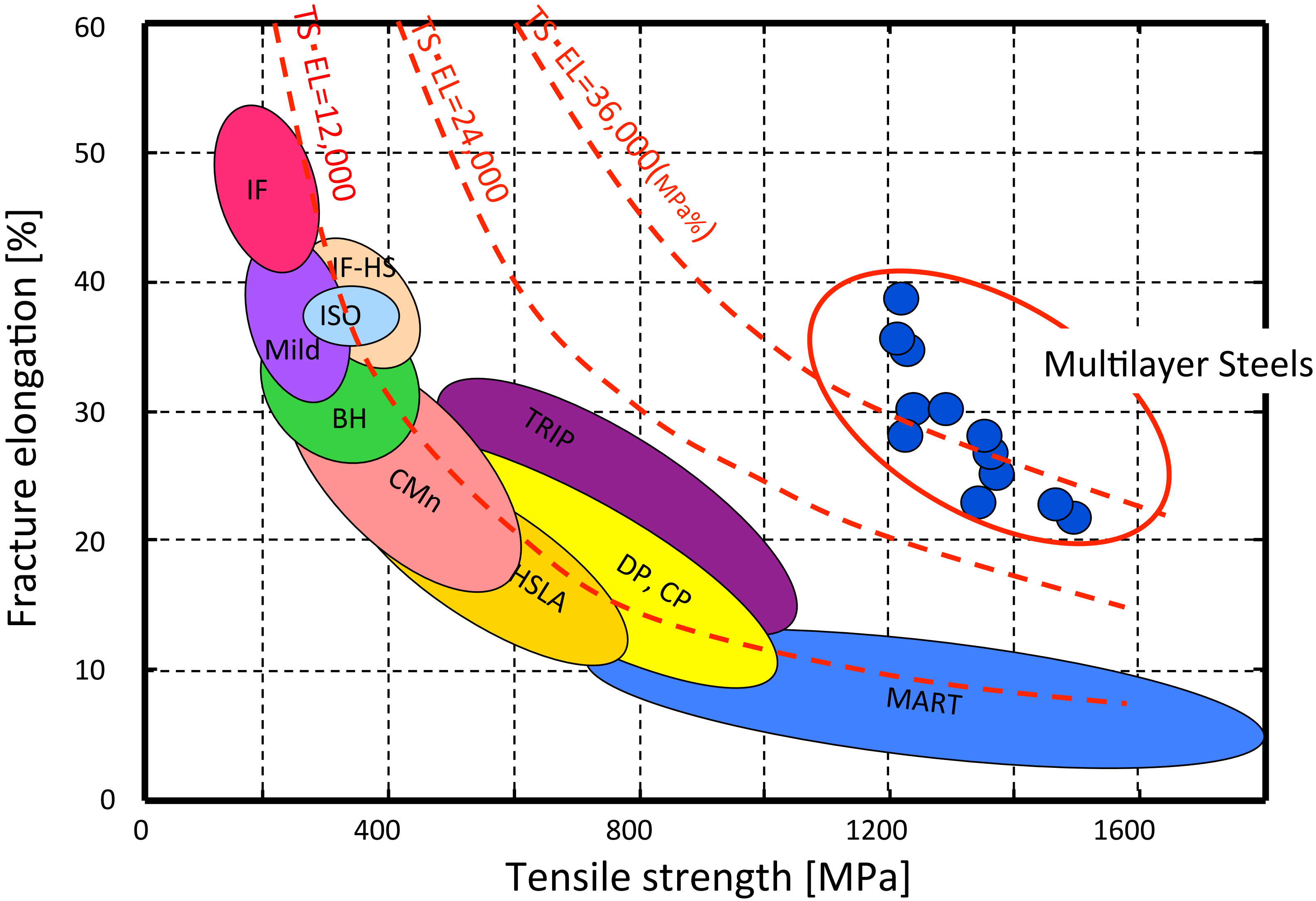
Elasto-plastic

$$t_B \leq \frac{2\sqrt{3}K_{IC}^2\sigma_Y}{\sigma^3}$$

Stress Partitioning

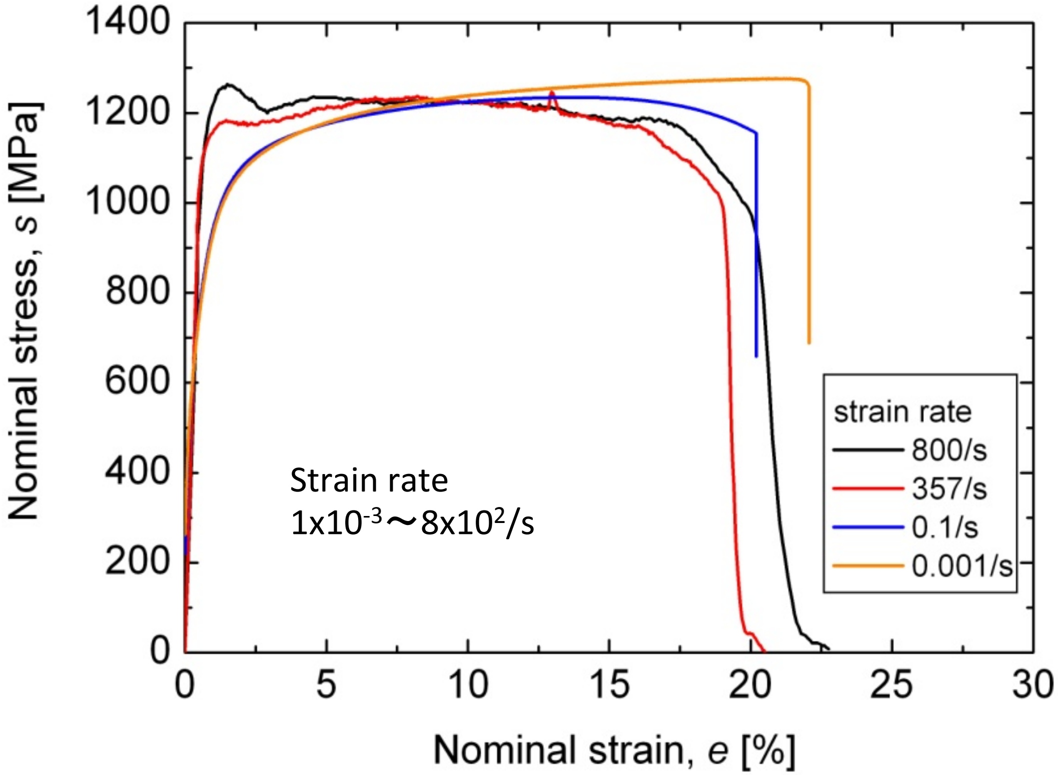


Strength-Ductility Combinations



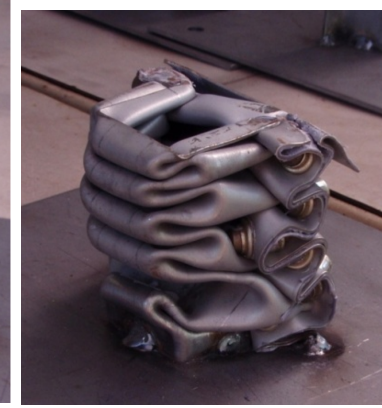
TS・EL = 30,000～50,000 (MPa%)

Deformation under High-Strain Rates



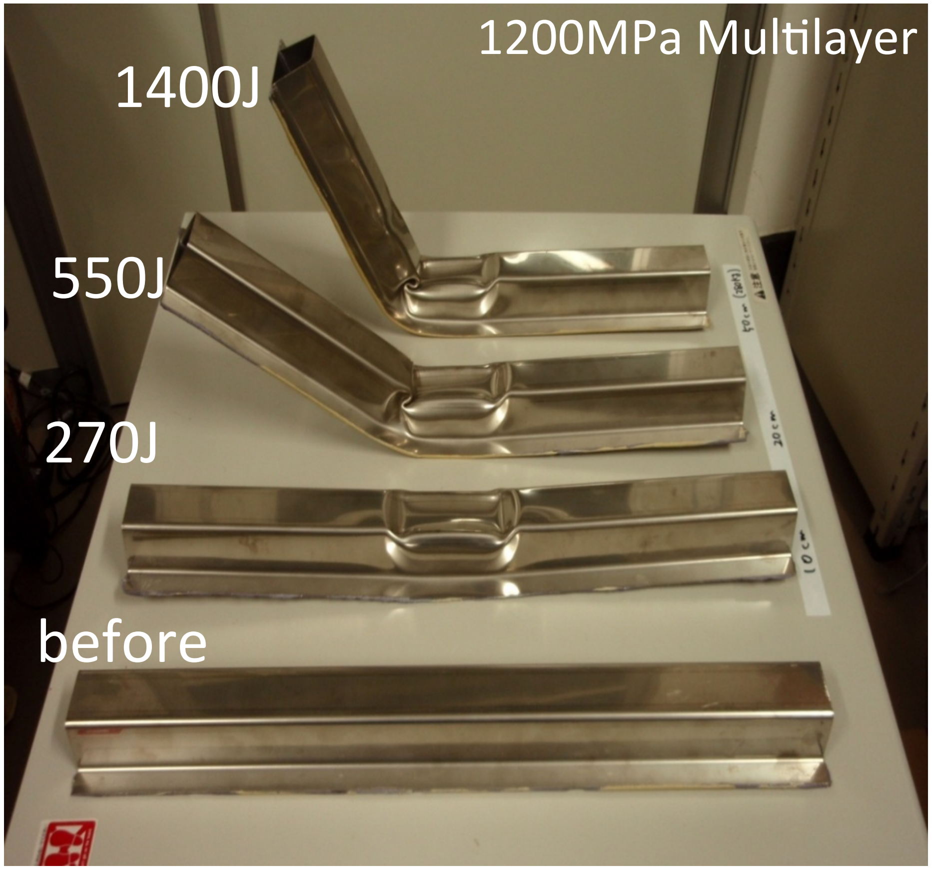
1200MPa
Multilayer

590MPa DP



Collision simulation
(High-speed buckling)

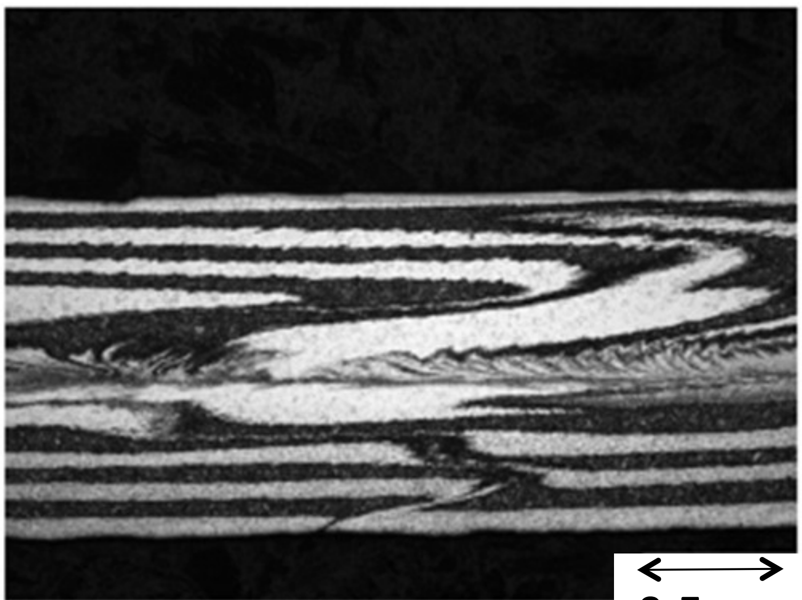
Impact Bending Tests



Welding and Joining

Friction Stir Welding

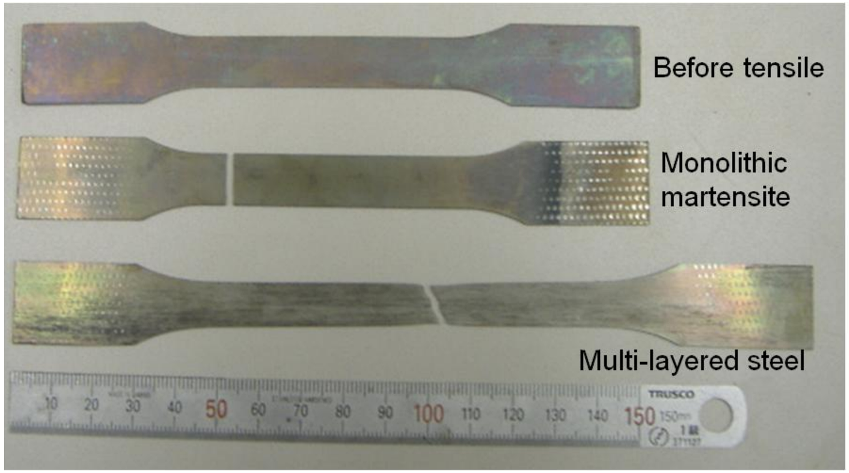
1mm

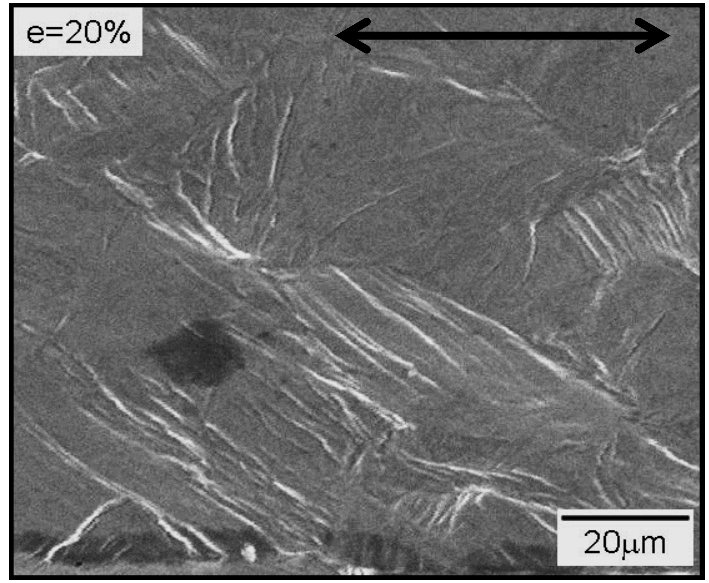


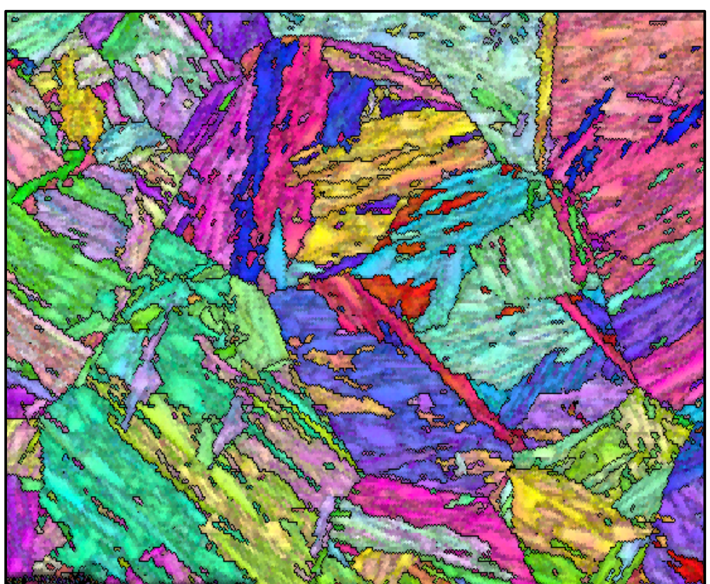
0.5mm

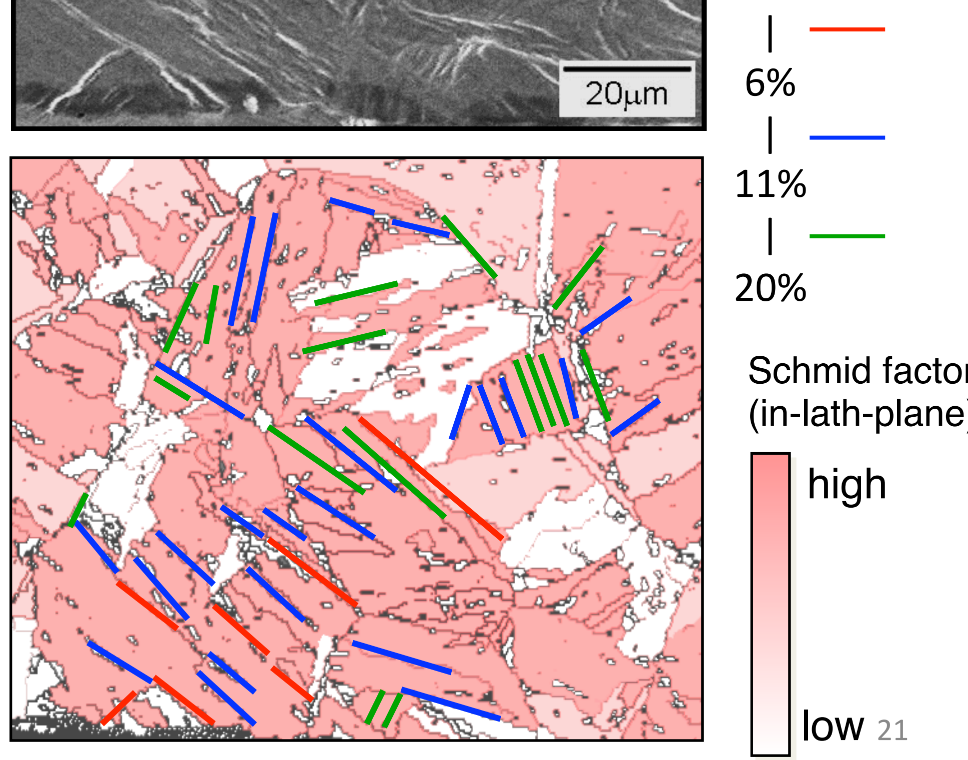
Joint Efficiency more than 90%

Deformation of Martensite

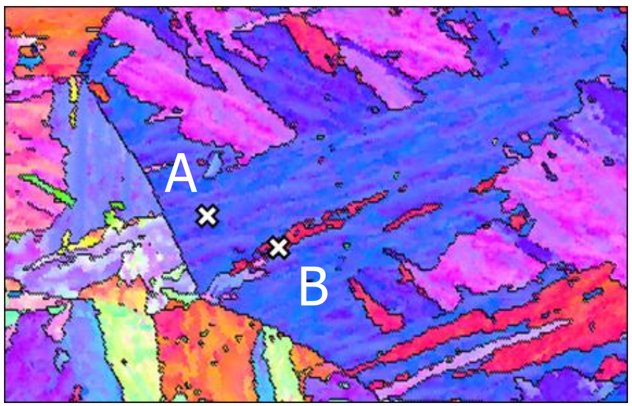




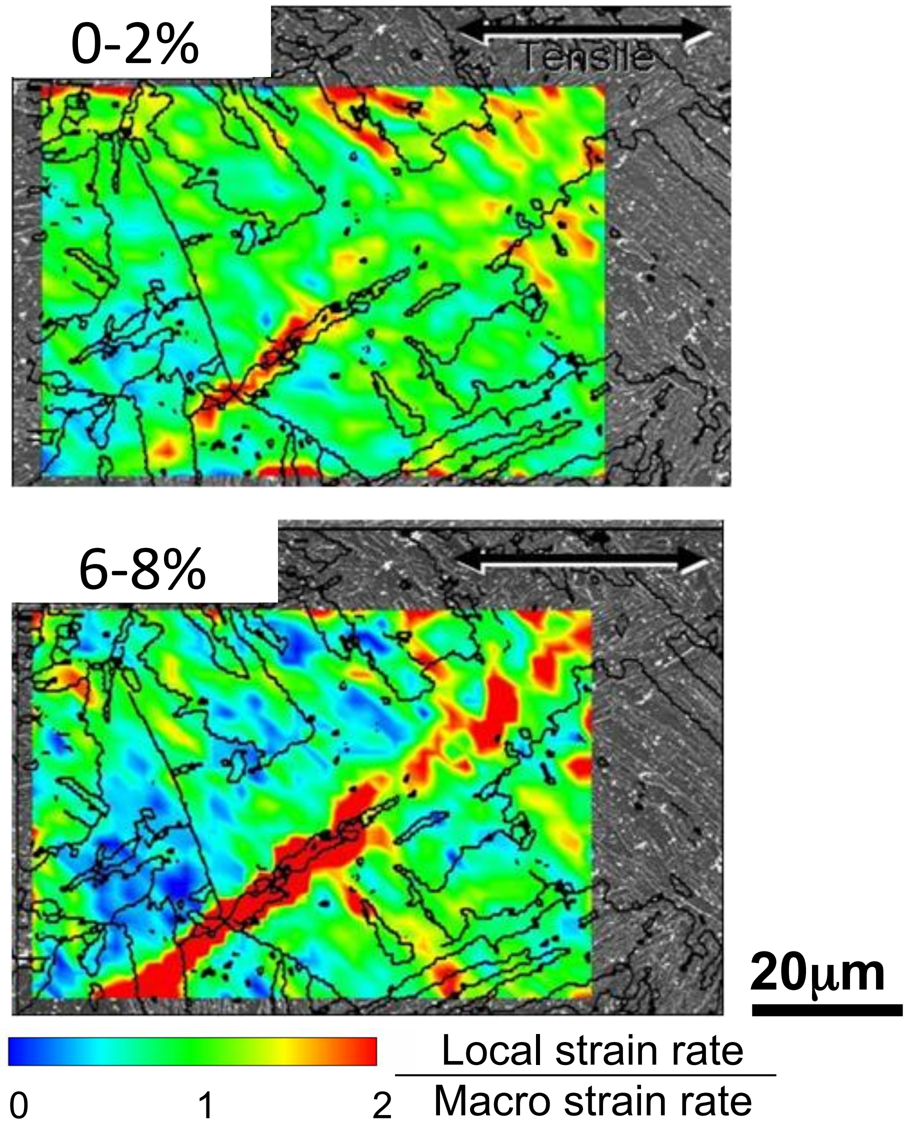




Strain Localization in Martensite



Point	Schmid factor		
A	0.494 Out	**0.434** **In**	0.431 Out
B	**0.484** **In**	**0.467** **In**	0.457 Out



Further Developments for Lighter & Environmental-friendly Steel

Process

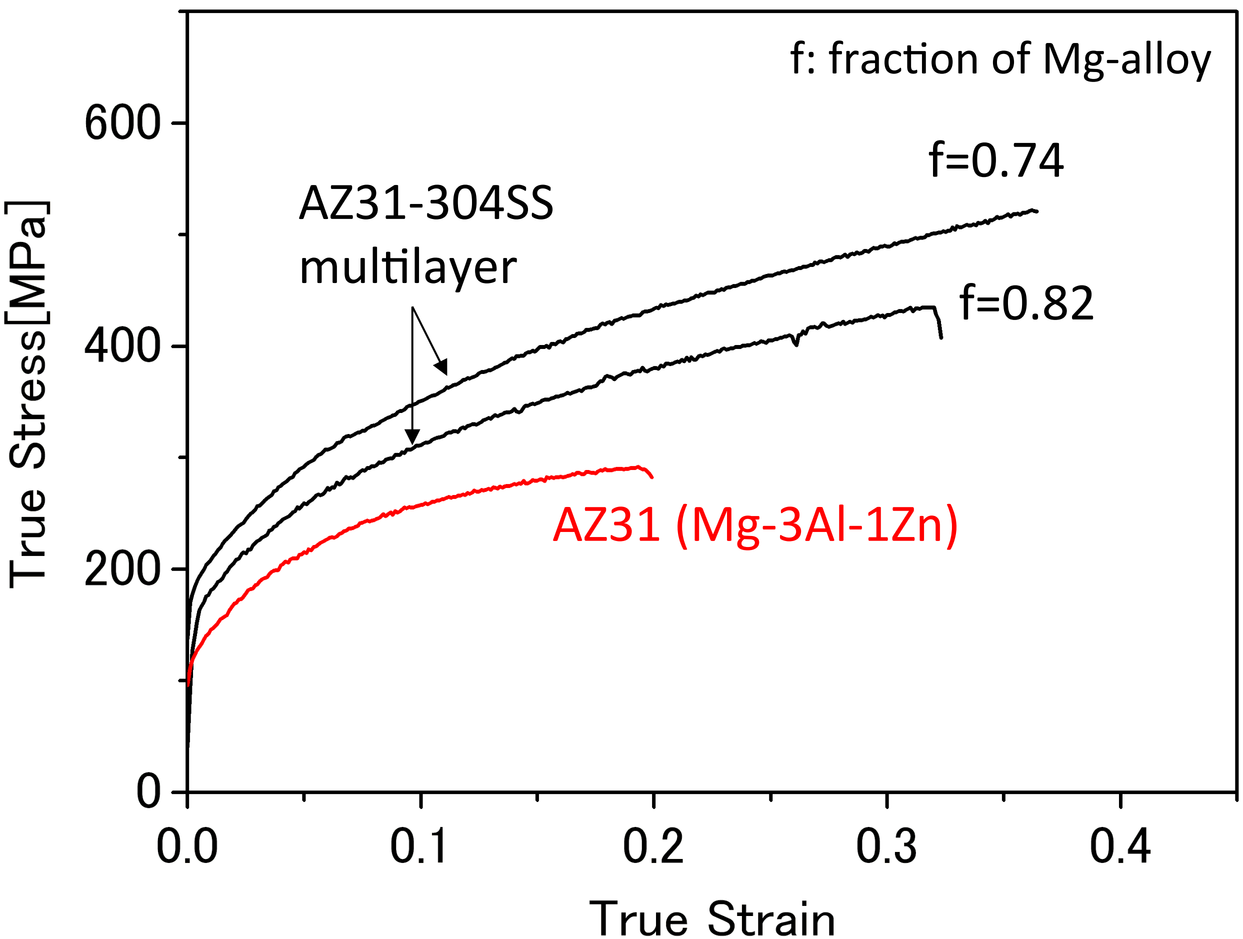
Low-temp., Low-Pressure Bonding

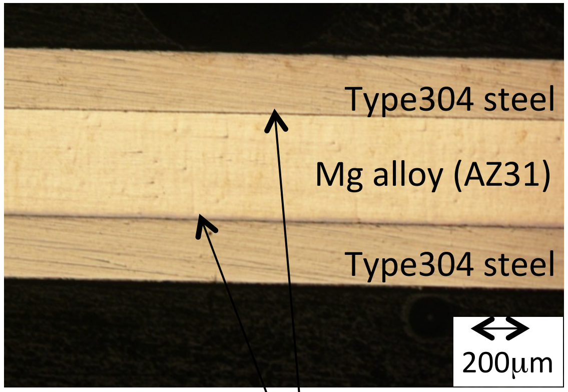
Component

Brittle/Low-ductility

- High-carbon Steel
- HCP Metals
- Steel with high impurities

Mg-Steel Multilayer





New Reactive
TLP Bonding

Summary

- Multilayer steel composites consisting of martensite layers and ductile layers are architected.
- High strength – elongation combinations are achieved by controlling the thickness of martensite layers and interfacial toughness between the layers.
- Deformation behaviors of as-quenched martensite is being clarified using multilayer steels up.
- The concept of multilayer steel is being extended to other component combinations.