Anisotropy of Charpy Properties in API-X80 Steels

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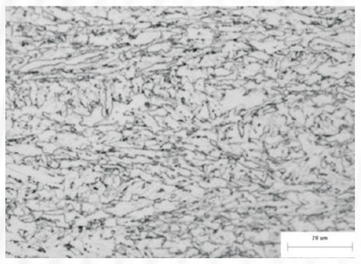
Anisotropy of Charpy properties has been investigated in API-X80 steels. Orientation dependence of impact property is hardly found in upper and lower shelf regions. In DBTT region, however, there was significant orientation dependence, and the specimen having orientation 45 degree to rolling direction exhibits lowest impact property. Delamination is observed at DBTT region except the specimen having 45 degree to rolling direction. Banded structure is observed consisting of allotriomorphic ferrite, acicular ferrite and other phases like M/A constituent and pearlite. The interface between microstructural bands plays an important role in initiating the delamination. The delamination contributes further plastic deformation and improves impact property in DBTT region. In the specimen having 45 degree to rolling direction, however, fast ductile to brittle transition is believed to suppress the occurrence of delamination, which is attributed to the higher density of grain which has {100} cleavage plane parallel to the fracture surface.

API-X80 Steel



Seo, D. H. *et al., 2007*

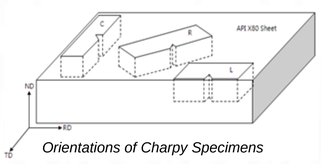
High strength with good low-temperature toughness

	Target	Result
Yield strength	≥ 551 Mpa	571~591 MPa
Tensile strength	620 ~ 827 Mpa	681~724 MPa
Yield Ratio	≤ 93 %	81~87 %
CVN Energy at -40˚C	≥ 110 J	300~350 J

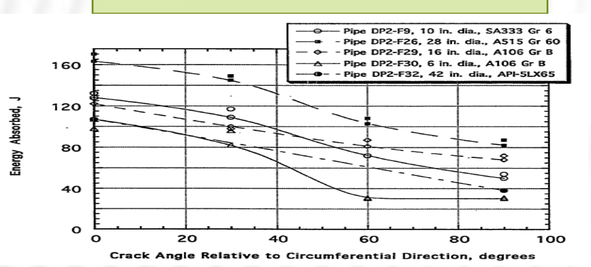
✓ **Fe-(0.05~0.07)C-0.25Si-~1.8Mn-~0.01P-~0.001S wt% with alloying elements Mo, Ni, Cu, Ti , Nb ,V.**
✓ Good Weldability - Ceq is 0.42 ~ 0.44.
✓ Microstructure is consists of acicular ferrite with martensite/austenite constituents.

Anisotropic behavior in Charpy toughness of API-X80 steel

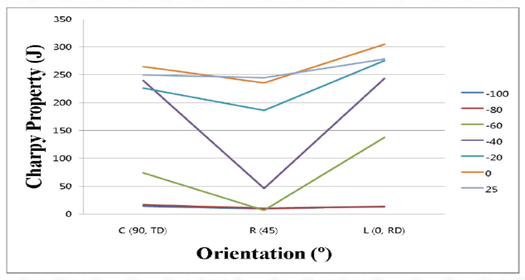
Mohan, R. *et al.,* NUREG/CR-6299, BMI-2184, 1995



Orientations of Charpy Specimens



Energy absorbed by Charpy V-notch specimens as a function of orientation
(Note: All fractions were 100 % ductile)



Anisotropic behavior in Charpy toughness of API-X80 steel

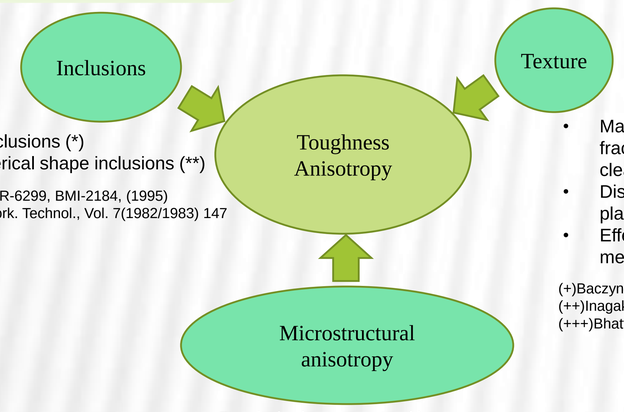
✓ Typical trends, the Charpy energy in transverse orientation is weakest at room temperature.

✓ The Charpy specimen having 45 degree to rolling direction exhibits lowest impact toughness.
✓ Isotropic behavior in both upper shelf and lower shelf region.
✓ Anisotropic behavior in DBTT region, R has poorest impact toughness.

Aim of the Work

To find the practical factors for the toughness anisotropy of API-X80 steel

Toughness Anisotropy



- Elongated inclusions (*)
- Array of spherical shape inclusions (**)

(*) Mohan, R. *et al.,* NUREG/CR-6299, BMI-2184, (1995)
(**) Imai, T. et al., J. Mech. Work. Technol., Vol. 7(1982/1983) 147

- Macroscopic texture, {112}<110> for ductile fracture, {110}<001> or {001}<110> for cleavage fracture (+)
- Distribution of grains which have {100} plane parallel to fracture plane (++)
- Effective grain size related to the mesotexture (+++)

(+)Baczynski, G. J. et al., Met. Mater. Trans. A, Vol. 30A ,(1999) 3045-54
(++)Inagaki, H. et al., Trans., ISIJ, Vol. 61(7), (1975) 83-103
(+++)Bhattacharjee, et. al., Ironmaking and Steelmaking, 30, (2003) 249-256

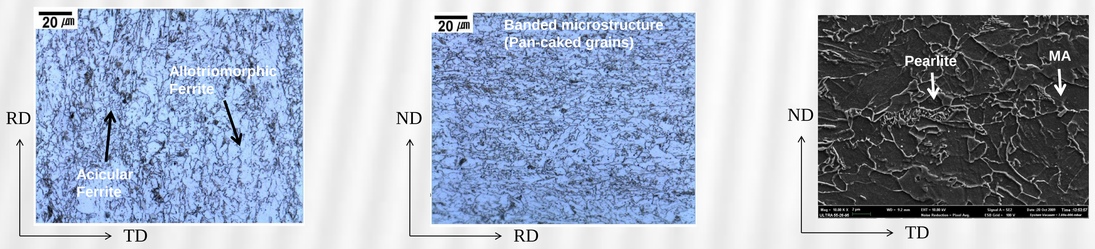
- Banded microstructure (-)
- Elongated grains (Anisotropy of grain-boundary densities along to the different directions) (--)

(-) Grange, R. A., Met. Trans., 2 (1971) 417
(--) Morrison, W. B., Met. Technol., (1975) 33

Experimental Results

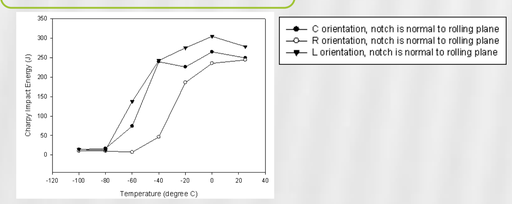
Microstructure of Target Steel

C	Si	Mn	P+S	Nb+Ni+Mo	Ti+Al	N
< 0.08	0.21	< 2.0	< 0.013	< 0.8	0.03	< 0.0036

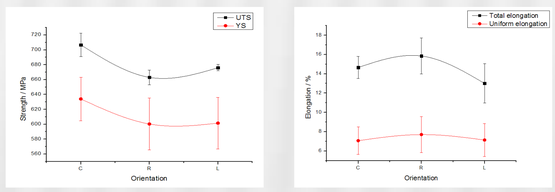


✓ Microstructure is consists of allotriomorphic ferrite and acicular ferrite with martensite/austenite constituents and pearlite.
✓ TD-ND, RD-ND planes show banded microstructure of allotriomorhpic ferrite - acicular ferrite.
(TD-ND and RD-ND planes are parallel to the fracture planes for L orientation and C orientation respectively.)
✓ Ferrite matrix is responsible for an high toughness when pearlite and M/A make bad effects on the toughness.

Mechanical properties



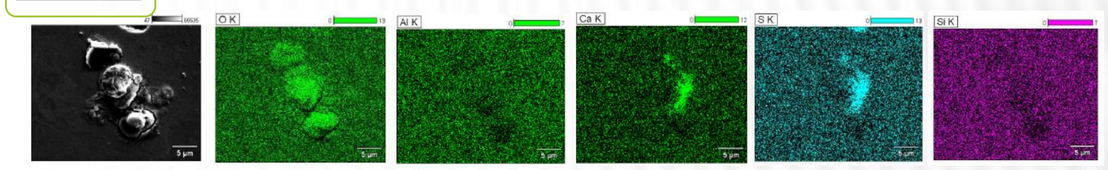
Toughness Curves of API-X80 steel



Tensile properties of API-X80 steel

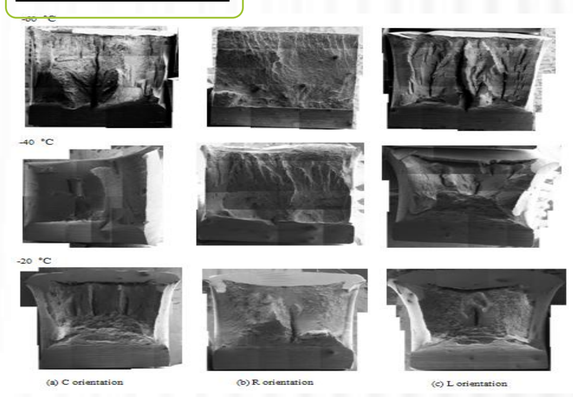
✓ Toughness curves show anisotropic behavior at DBTT region (R orientation has highest DBTT) when isotropic manner appears at upper and lower shelves.
✓ R has lowest toughness and strength (NOT TYPICAL).
✓ Total elongation curve is compatible with strength curve but uniform elongation show almost isotropic behavior.

Inclusions



✓ Cluster of complex oxides with calcium sulphide was found in all planes (RD-TD plane normal to ND) and 3 planes parallel to fracture planes of L, R and C orientation specimens).
✓ Oxides show spherical shape, no elongated, no banded and no arrayed.
→ Compatible with isotropic manner in upper shelf region and is not related to the anisotropy.

Fracture surfaces

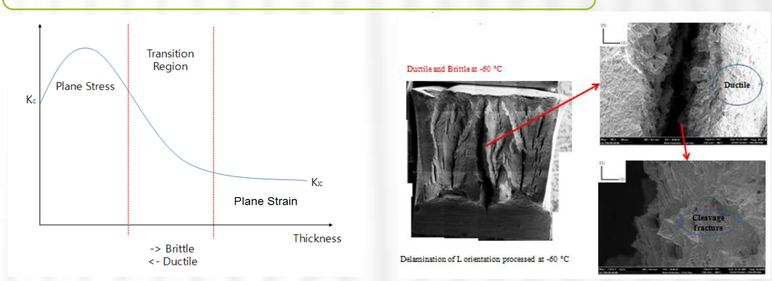


Delamination phenomenon

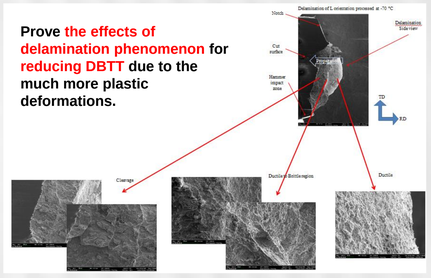
- Effects
  - ✓ Lower the upper shelf energy and DBTT
- Factors
  - ✓ Elongated inclusions such as MnS
  - ✓ Intergrannular failure along prior austenite boundaries due to the segregation of P and S
  - ✓ Banded microstructure, elongated grains due to the rolling process
  - ✓ Texture

✓ R orientation has no delamination phenomena at -40 and -60 ˚C (DBTT region)

Mechanism for lowering DBTT by delamination

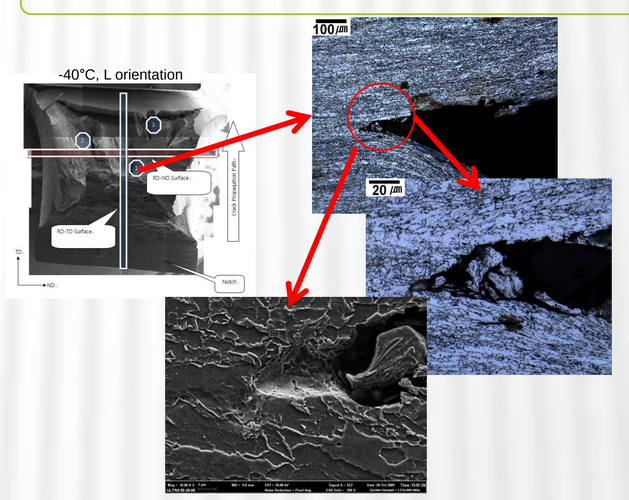


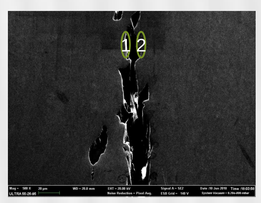
Prove the effects of delamination phenomenon for reducing DBTT due to the much more plastic deformations.

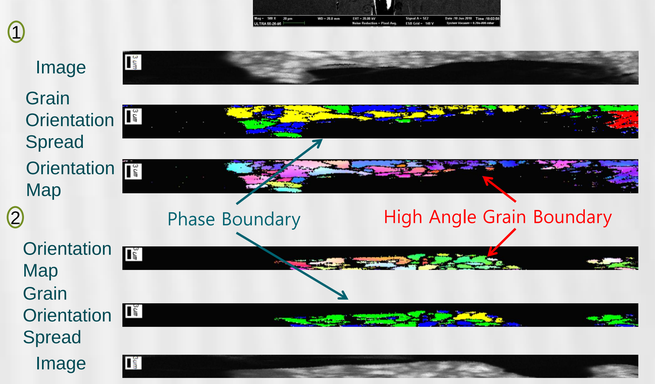


✓ The change of the stress intensity factor as a function of sample thickness.
✓ Delamination makes several thinner planes which can undergo plastic deformation better.

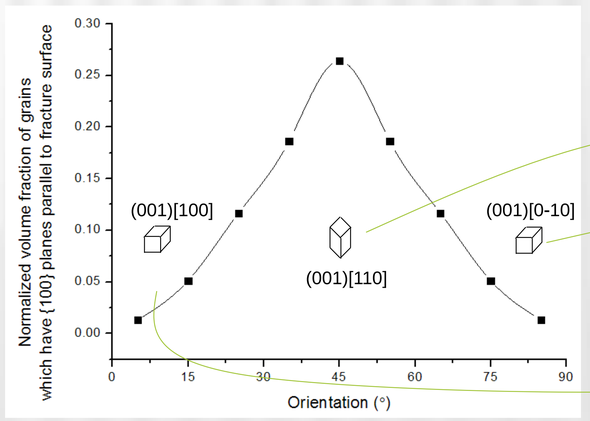
Delamination comes from banded microstructure

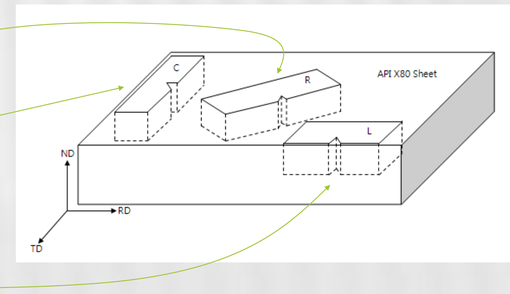






Fast ductile to brittle behavior by volume fraction of grains having {100} planes parallel to fracture surface





Summary

✓ The anisotropy of Charpy properties in API-X80 steel was investigated.
✓ API-X80 steel has two main factors for toughness anisotropy, the one is the delamination phenomenon and the other is the texture.
✓ Delamination reduces the DBTT in L and C orientations.
✓ Much more volume fraction of grains having {100} planes parallel to fracture surface is believed to suppress the occurrence of delamination phenomenon in R orientation and leads rapid ductile to brittle transition.

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