Investigation of anisotropy in elastic modulus of steel

Umesh Gandhi

Toyota Research Institute, NA. Toyota Technical Center, Ann Arbor, Mi

@ Workshop on

Addressing Key Technology Gaps in Implementing Advanced High-Strength Steels for Automotive Lightweighting

February 9 - 10, 2012 | USCAR Offices | 1000 Town Center, Suite 300 – Southfield, MI

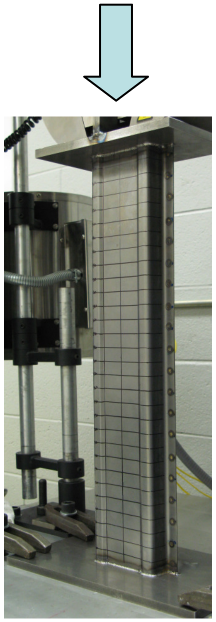
Steel Market Development Institute · A/S P Auto/Steel Partnership · NIST National Institute of Standards and Technology · Pacific Northwest National Laboratory · Oak Ridge National Laboratory

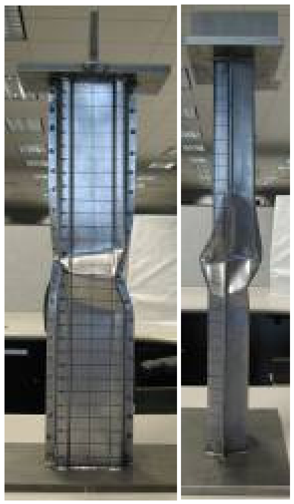
Toyota Technical Center - AnnArbor

Investigation of anisotropy in elastic modulus of steel

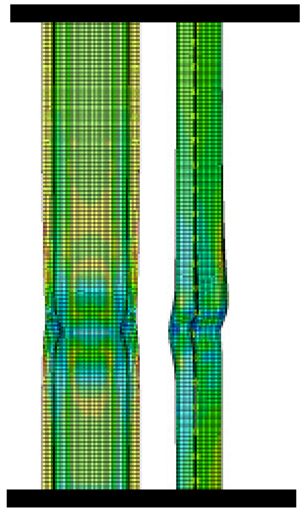
1. Background
2. Variation in the Young's modulus of steel
3. Root cause of variations in the Young's modulus
4. Impact of anisotropy in steel in design
5. Conclusions
6. Future challenges

1. Background

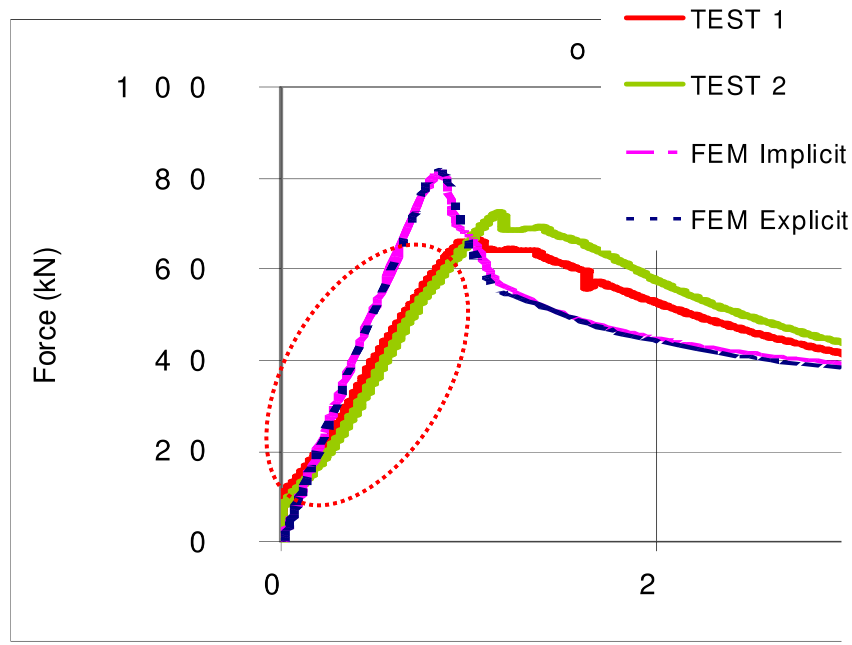




SIDE



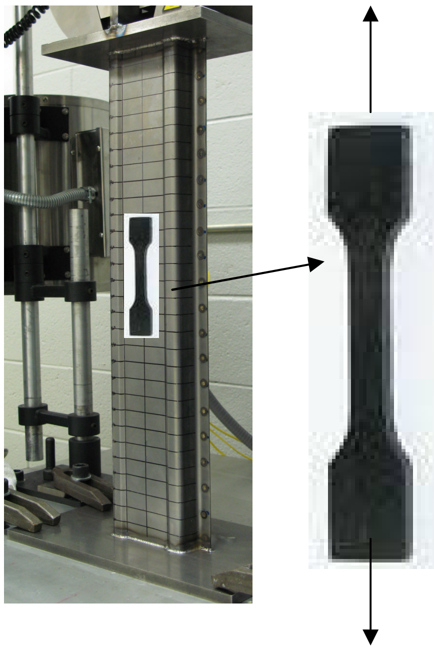
SIDE

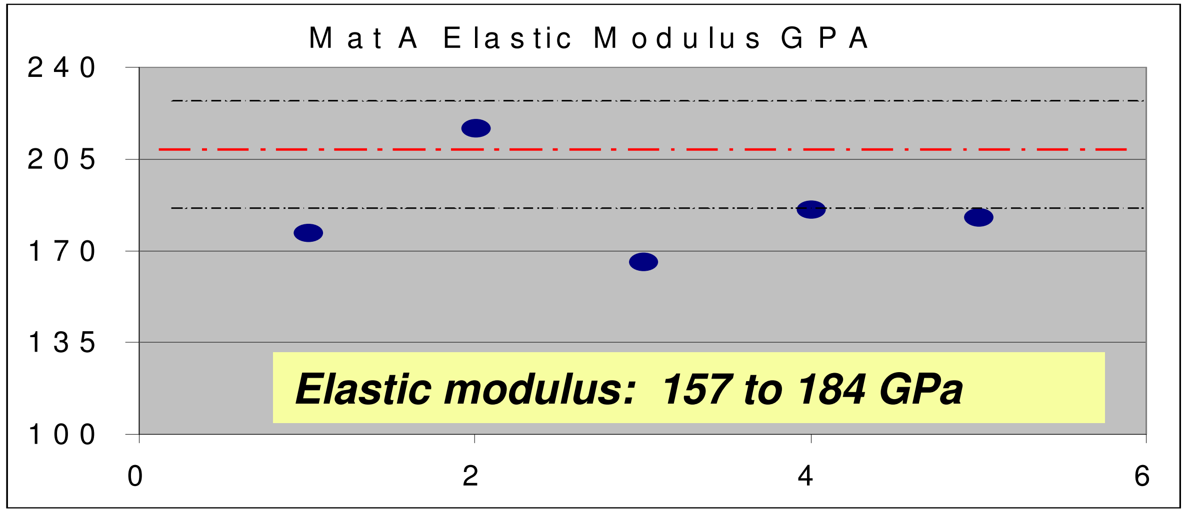


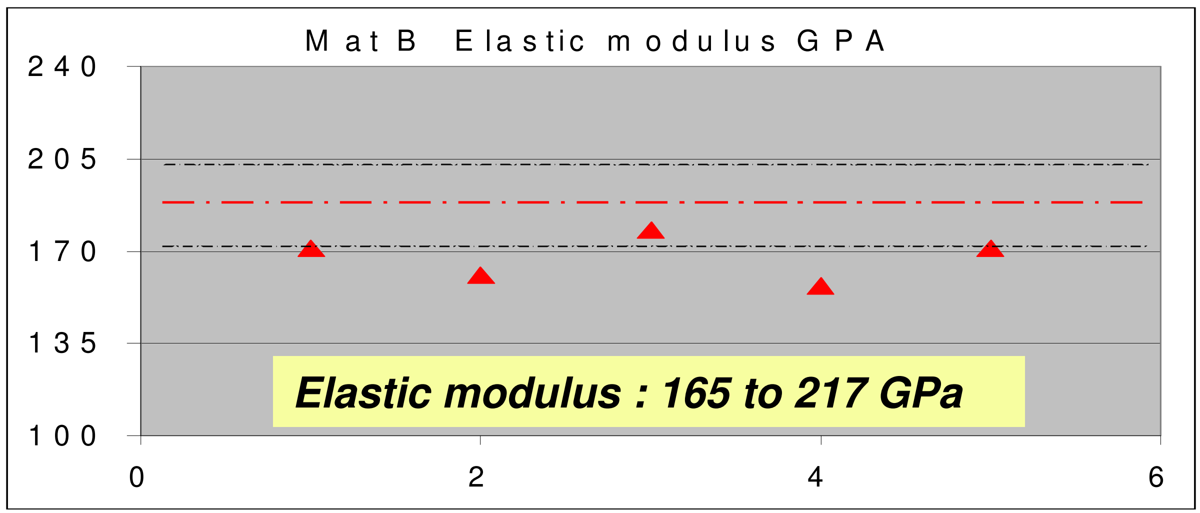
Source	Non linear Implicit	Non linear explicit	Test 1	Test 2
Max load (kN)	81.5	82	66.5	72.7

The force crush in elastic region did not match in simple compression test

1. Background



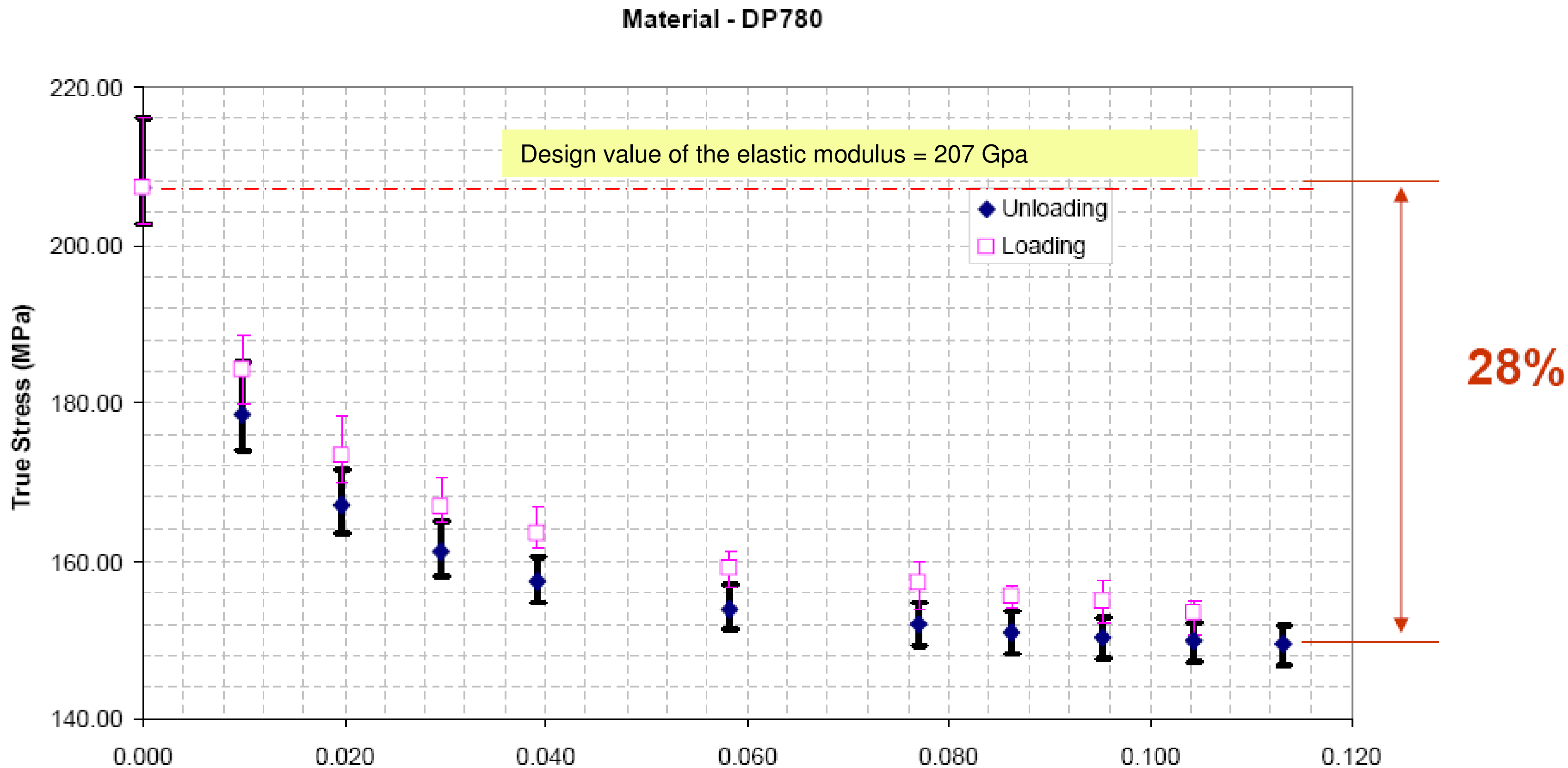




Design value of the elastic modulus = 207 GPa

2. **Variation in the Young's modulus of steel**

<u>EWI study of DP780 Steel</u>

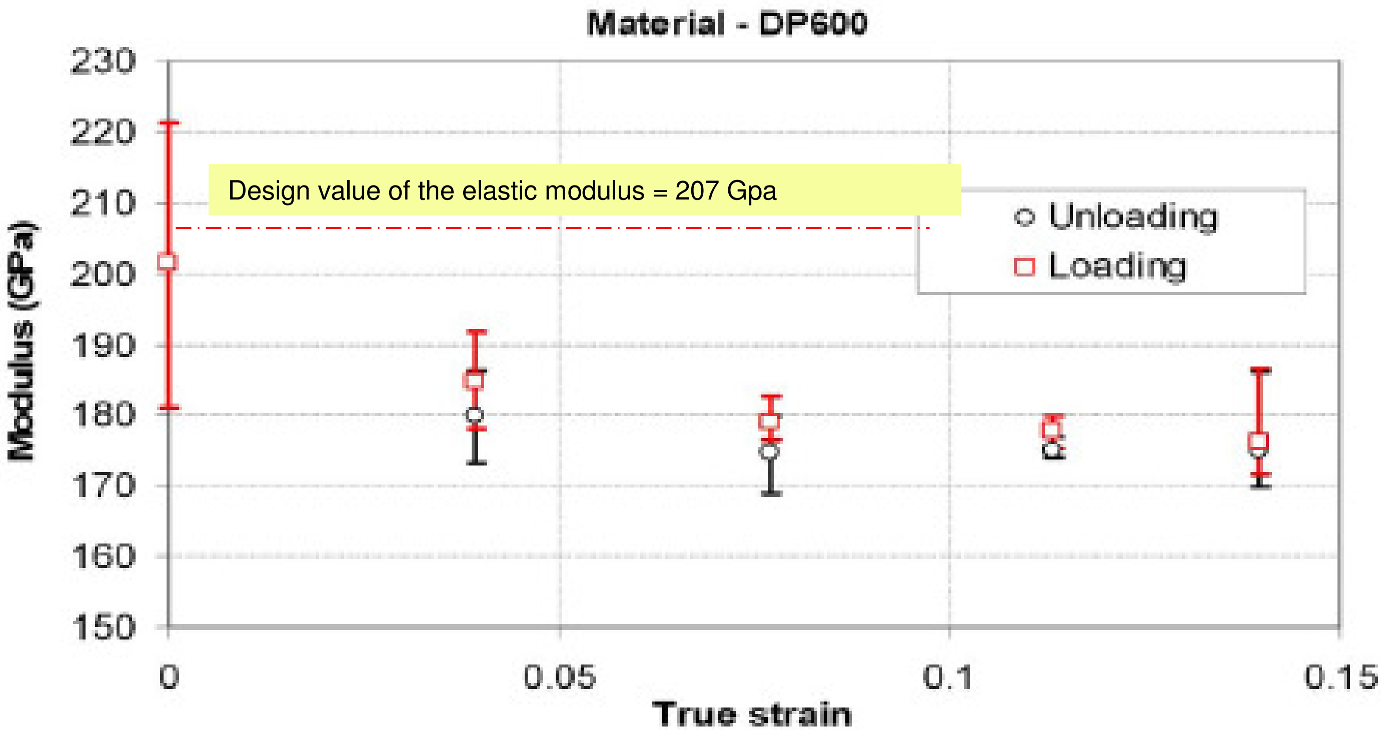


Reference : Hyunok Kim1, Menachem Kimchi1 and Taylan Altan2
Control of Springback in Bending and Flanging Advanced High-Strength Steels (AHSS)

Published paper from EWI also shows similar trend

2. **Variation in the Young's modulus of steel**

EWI study of DP600 Steel

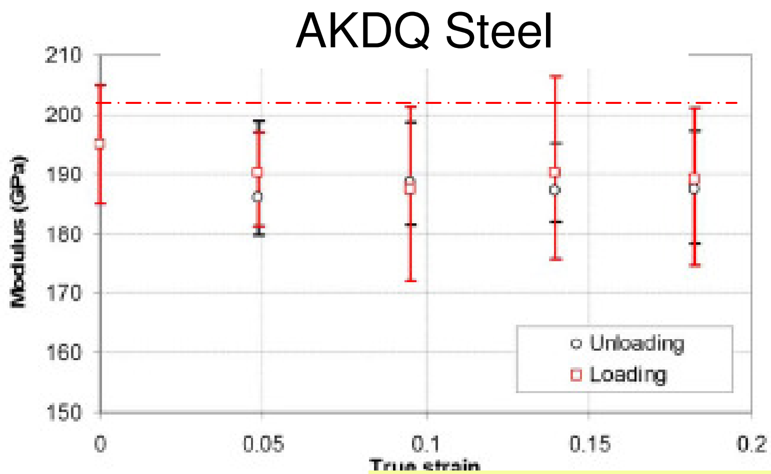


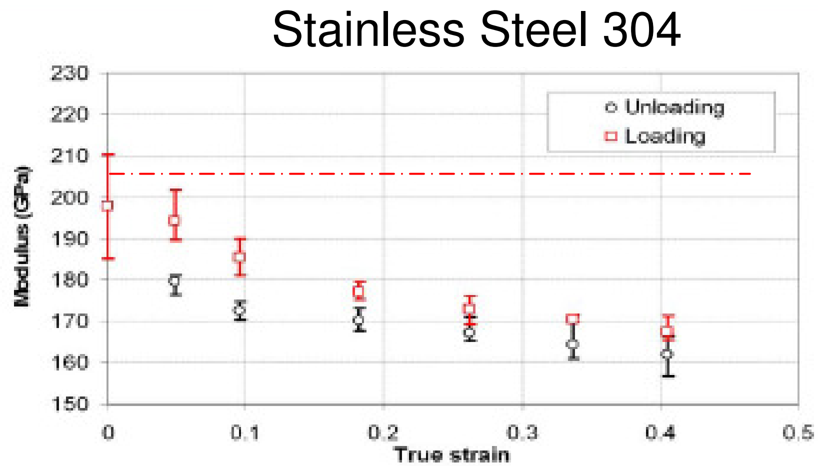
Reference : Hyunok Kim1, Menachem Kimchi1 and Taylan Altan2
Control of Springback in Bending and Flanging Advanced High-Strength Steels (AHSS)

Published paper from EWI also shows similar trend

2. **Variation in the Young's modulus of steel**

<u>High strength steels</u>





Design value of the elastic modulus = 207 Gpa

'Measured' Elastic modulus varies in all type of steel !

Reference : Hyunok Kim1, Menachem Kimchi1 and Taylan Altan2
Control of Springback in Bending and Flanging Advanced High-Strength Steels (AHSS)

AKQD : Aluminum killed draw quality

3. Root cause of variations in the *'measured'* elastic modulus

1) **Test method variations**

   - **Variation for simple cupon test are too high, due to small and often non linear initial slope.**

2) **Anisotropic of Material**

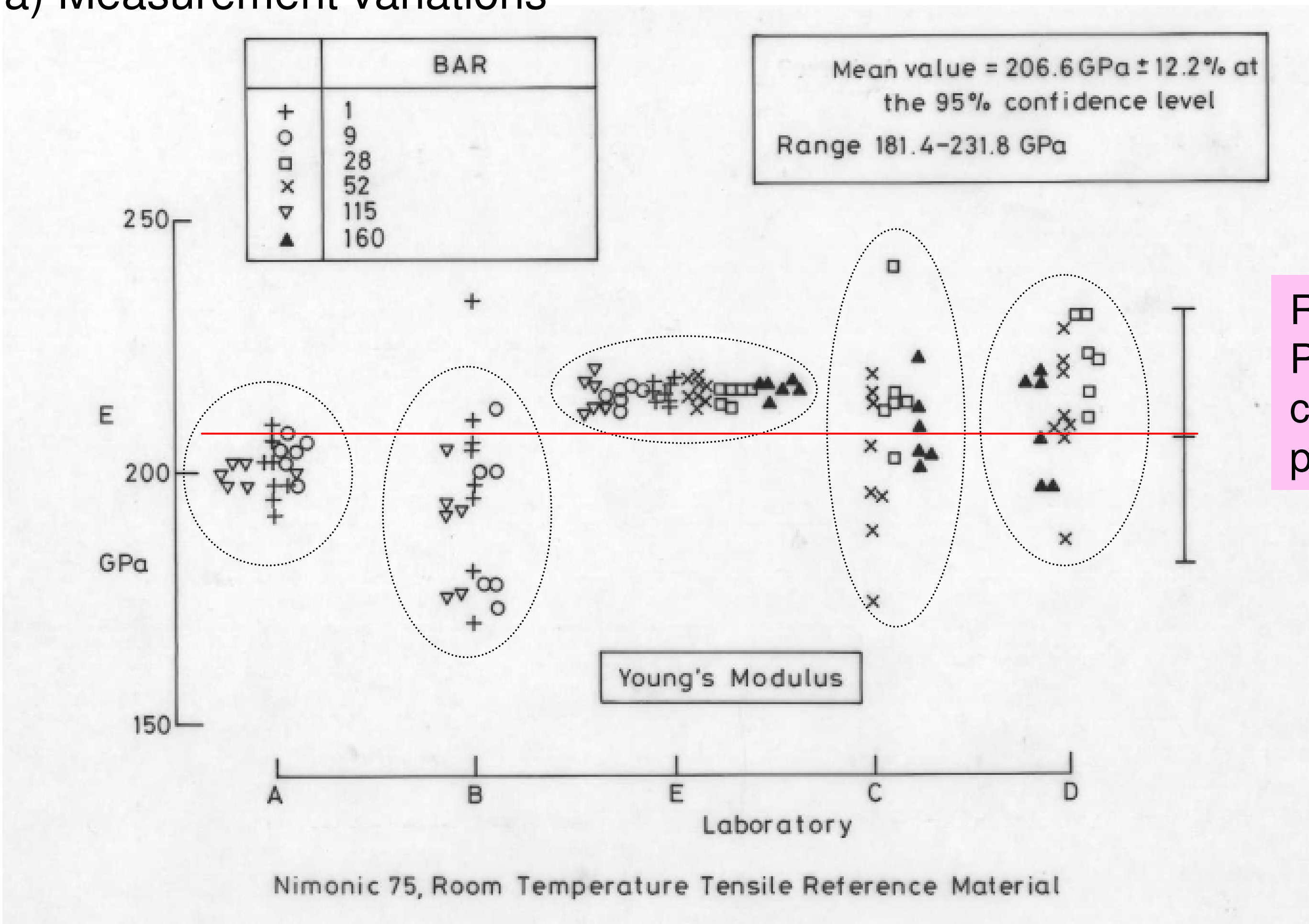
   - **Steel crystal is highly anisotropic**

For Most CAE calculations we use

Elastic modulus for steel = 207 GPa, isotropic

3. Root cause of variations in the *'measured'* elastic modulus

a) Measurement variations



Results from EU Project to develop computerized test procedure

*"**Young's Modulus measurement** - Various studies show that the minimum standards specified for testing machines are inadequate for accurate measurement of Modulus and the standard tensile test is not the ideal method to determine this property. "*

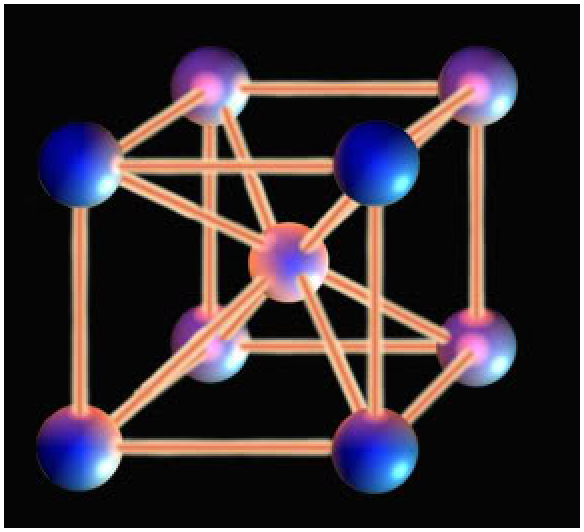
Ref : Tensile Testing of Metallic Materials: A Review Malcolm S Loveday, Tom Gray and Johannes Aegerter, 2004, EU Project

3. Root cause of variations in the *'measured'* elastic modulus

Elastic modulus of iron crystal ?

Anisotropy ratio =0.41

Single crystal of α iron (ferrite) is anisotropic.



E_{111}= 276 GPA,

E_{100}= 129 GPA

Averaged for poly-crystal

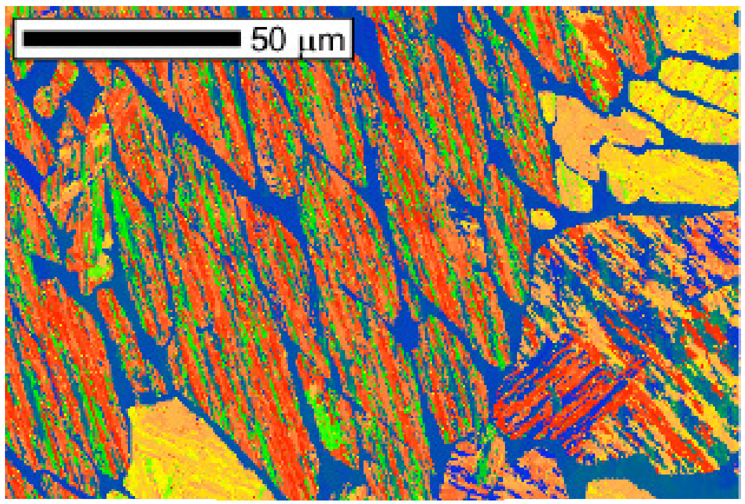
$E_{average}$ = 209 GPA

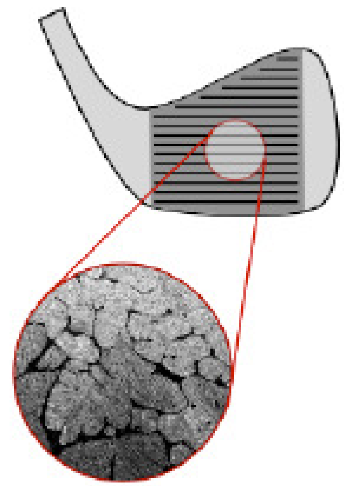
Ref : Mechanical behavior of materials, by Courtney

3. Root cause of variations in the *'measured'* elastic modulus

Effect of crystal anisotropy on iron parts ?

- **Orientation of grain can be measured using EBSD Microscopy**
- **Based on orientation of grain the elastic modulus is estimated as follows**





EBSD : Electron beam scatter diffraction

95 Gpa **235 Gpa**

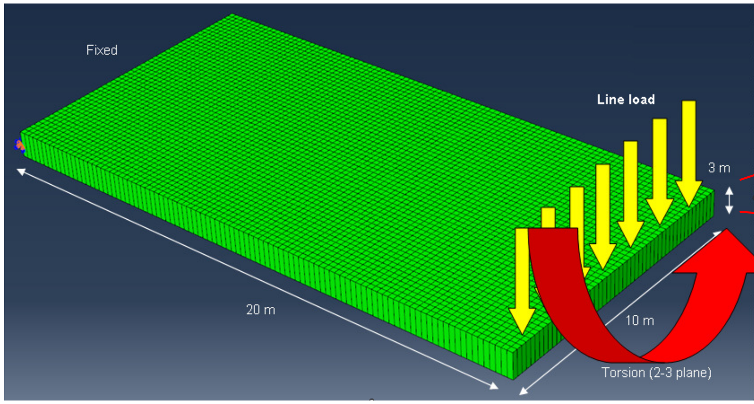
Ref : Stuart I. Wright and Matthew M. Nowell, *EDAX-TSL,* Elastic Modulus Mapping of Golf Club Heads

Comments:

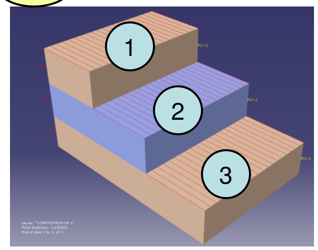
Elastic modulus varies depending of the

4. Impact of anisotropy in steel on design

Example : Simple steel plate

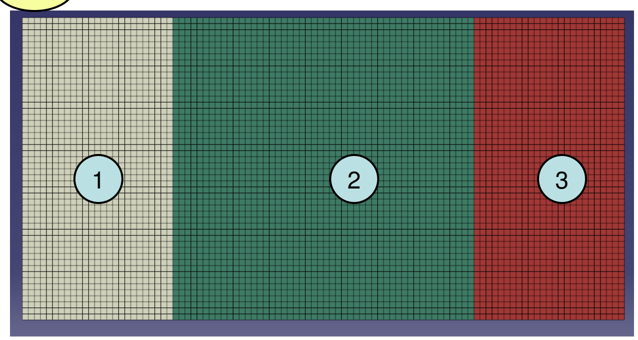


A



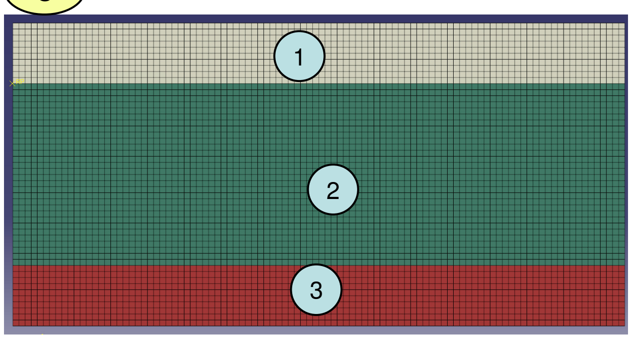
Variation through the thickness

B



Variation through the length

C

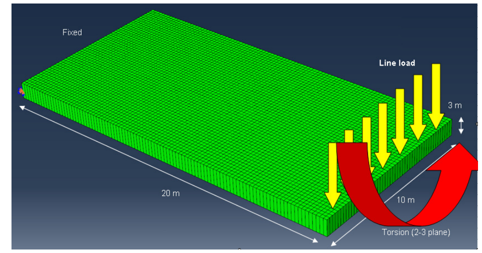


Variation through the width

		Normal Mode	def. of Bending	def. of Twist (m)	1	2	3
A	case1	6.23	5.59	0.39	207GPa	207GPa	207GPa
A	case2	6.55	5.07	0.35	230GPa	207GPa	230GPa
A	case3	6.18	5.74	0.41	230GPa	207GPa	180GPa
A	case4	5.85	6.32	0.43	180GPa	230GPa	180GPa
B	case5	6.02	5.85	0.39	180GPa	230GPa	180GPa
B	case6	5.94	6.04	0.39	180GPa	207GPa	230GPa
C	case7	6.22	5.62	0.40	180GPa	207GPa	230GPa
C	case8	6.13	5.81	0.43	150GPa	207GPa	230GPa

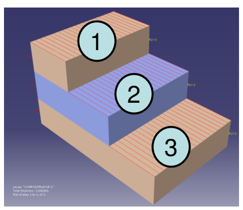
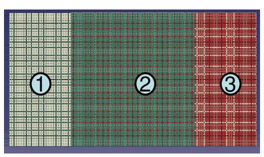
Note : Simulation only to demonstrate effect of variations in elastic modulus on design

4. Impact of anisotropy in steel on design



Results :

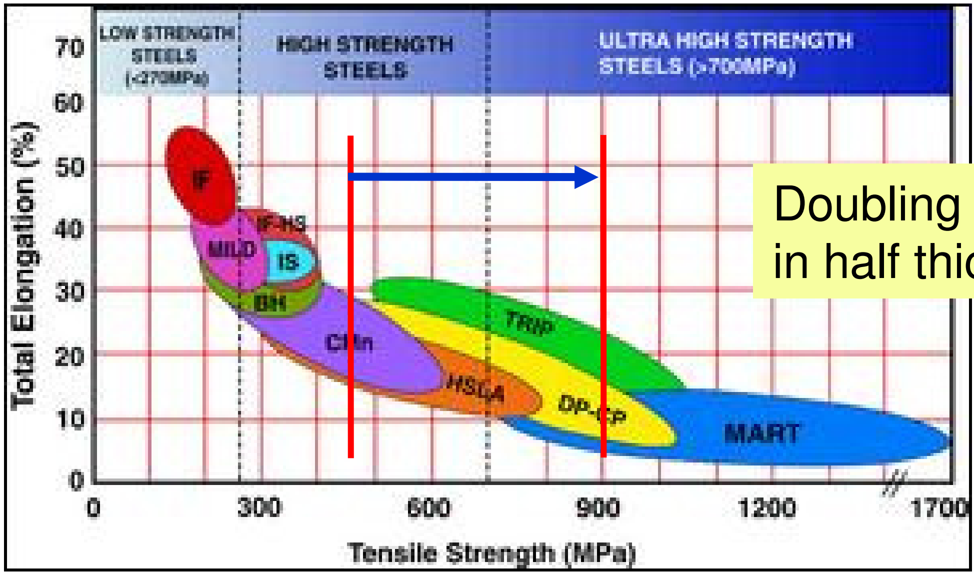
Following is predicted difference in mechanical properties for variation through thickness.

Variations Range : 180-230Mpa				Normal mode	Bending	Twisting
	Mat 1 230 207 230	v/s	Mat 2 180 230 180	9.2 %	20%	19%
	Mat 1 150 207 230	v/s	Mat 2 180 207 230	1.5%	3.3%	7%

- **Variation of elastic modulus of ➔ significant variations in the mechanical properties.**
- **Knowing the elastic modulus steel usage can be optimized to save weight.**

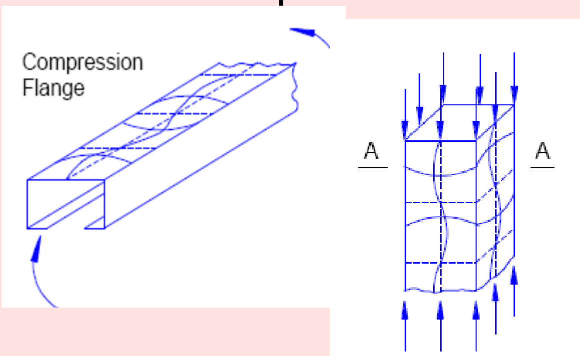
4. Impact of anisotropy in steel on design

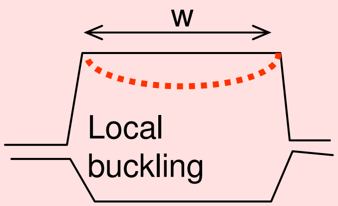
Full use of higher YS from AHSS



Doubling YS does not result in half thickness

Under compression the thin wall buckles





Buckling load =

Elastic modulus x Section modulus

Higher elastic modulus results in lower Section modulus

➔ Lower weight

5. Conclusions

1. **The 'measured' steel modulus easily varies by from 180-220 GPa.**
2. **The variation in the steel modulus is due to**
   - **Variations in measurements**
   - **Grain structure orientation in steel (anisotropy)**
3. **It is important to understand the variations in steel modulus to optimize use of steel in automotive applications**

6. Future Challenges

a) How to measure Elastic modulus of steel ? i.e. A repeatable, reliable, low cost method is desired.

b) How to measure grain structure in 3D ?

c) How to estimate elastic modulus from grain structure, e.g. based on grain size, composition and orientation ?

d) How to quantify effect of different manufacturing processes on the elastic modulus of steel.

e) How to control – elastic modulus, during processing, so the anisotropy in steel can be tailored to optimize and help reduce weight.

Thank you