Development of Improved Formability Interstitial Free Steels

Talal Said Abdullah – 3rd Year Eng.D

Prof Steve Brown[1], Prof Nick Lavery[2]

Dr Geraint Lodwig[3]

Prifysgol Abertawe Swansea University

TATA STEEL

UKRI Engineering and Physical Sciences Research Council

Undeb Ewropeaidd European Union

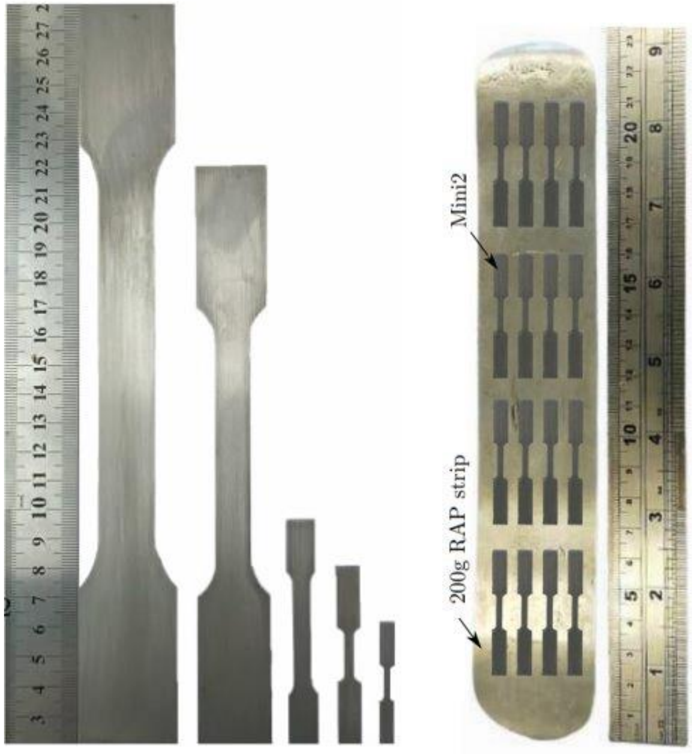
Llywodraeth Cymru Welsh Government

Cronfa Gymdeithasol Ewrop European Social Fund

Agenda

In this presentation:

1. Material
2. Testing procedure an established method
3. Scaling effects on the r-value
4. Drawbacks
5. Overall purpose



Interstitial Free (IF) Steels – DX57

- Interstitial Free (IF) steel - DX57
  - Excellent formability & low strength
  - Ferritic Microstructure
  - Grain size of *20µm- 50µm*

- Application
  - Automotive - Complex, formed body exterior & interior

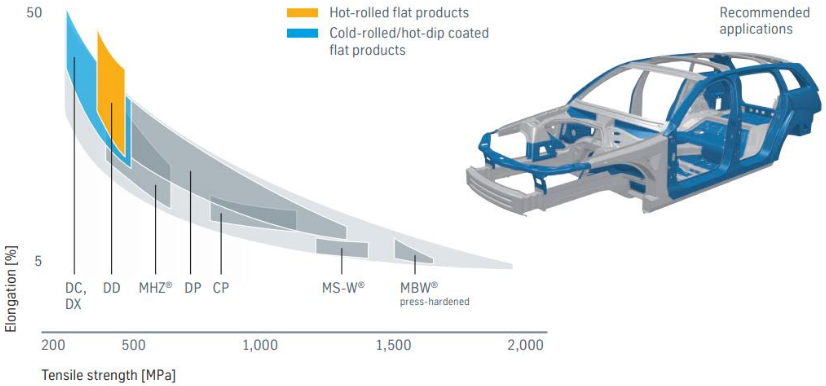


Figure 1 *: Graph of steel grades, on the right is the diagram of the IF's automotive application.*

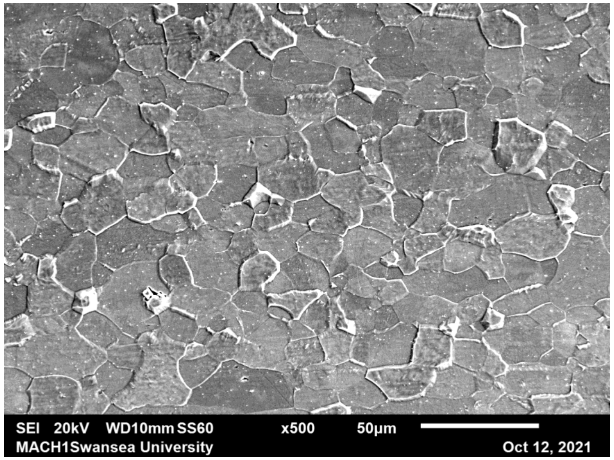


Figure 2*: SEM image of the DX57 ferritic microstructure on the cross-section. Image shows grain size (d_0) ranging from 20µm- 50µm.*

Rapid Alloy Prototyping (RAP)

- Industrial scaled testing – Slow & expensive
- Significantly scaled down production/testing process
  - 20 - 200 g casts
  - Non-standard Miniaturised tensile specimens (MTS); Mini 1 & Mini 2
- But can we achieve representable results?

***Table 1** : Dimensions of the standard and non-standard tensile specimens.*

Specimen profile	Length, L_t (mm)	Gauge Length, L_0 (mm)
A80	260	80
A50	200	50
ASTM 25	100	25
Mini 1	60	10
Mini 2	41	5

BSI, BS EN ISO 6892-1:2009; Metallic materials - Part 1: Method of test at ambient, British Standards, 2009, pp. 1-65.
  a. A80
  b. A50

ASTM, E8/E8M – 09: Standard Test Methods for, American Association State, 2010, pp. 1-27.
  a. ASTM 25

L. Zhang et al. "The development of miniature tensile specimens…", *Journal of Materials research and technology* , vol. 15, pp. 1830-1843, 2021.
  a. Mini 1
  b. Mini 2

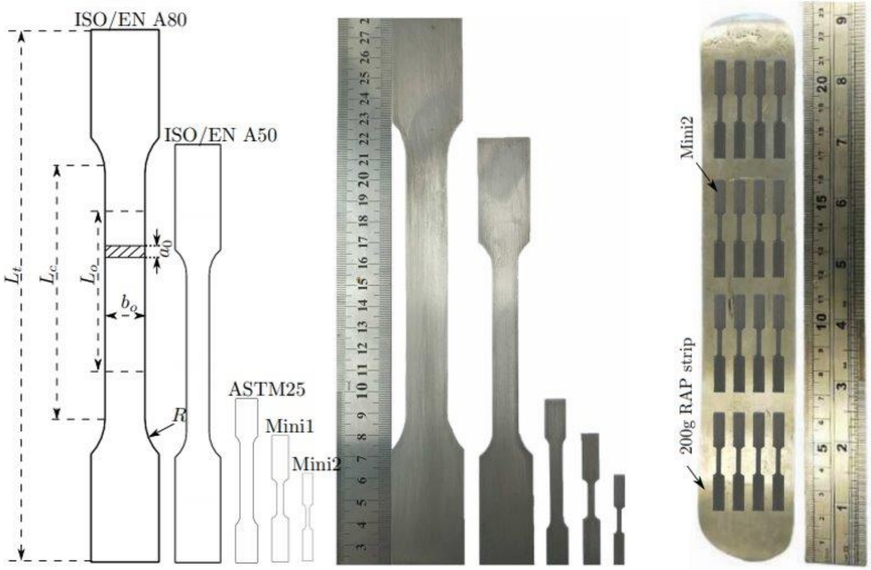
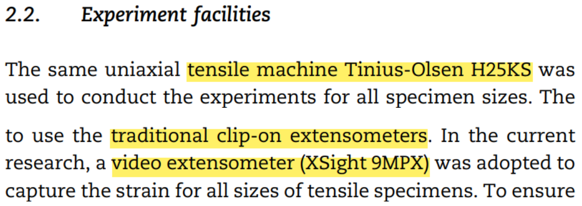


***Figure 3** : Visual representation of the specimen sizes relative to each other.*

Equipment

- Tinius Olsen H25KS Tensile test machine
- XSight One video extensometer
  - Tracks the change in length and width by pixels, ***figure 4(b)***
  - Measure longitudinal and transverse strain
- Transverse mechanical extensometer
- Samples: A80 – Mini 2

L. Zhang et al. "The development of miniature tensile specimens…", *Journal of Materials research and technology* , vol. 15, pp. 1830-1843, 2021.



2.2. *Experiment facilities*

The same uniaxial tensile machine Tinius-Olsen H25KS was used to conduct the experiments for all specimen sizes. The

to use the traditional clip-on extensometers. In the current research, a video extensometer (XSight 9MPX) was adopted to capture the strain for all sizes of tensile specimens. To ensure

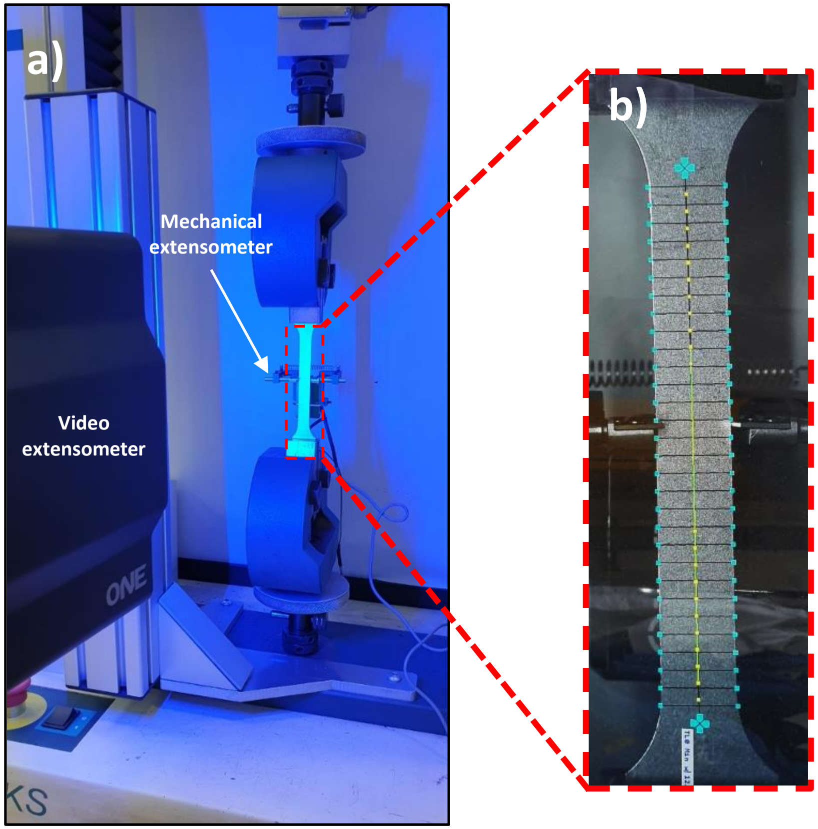
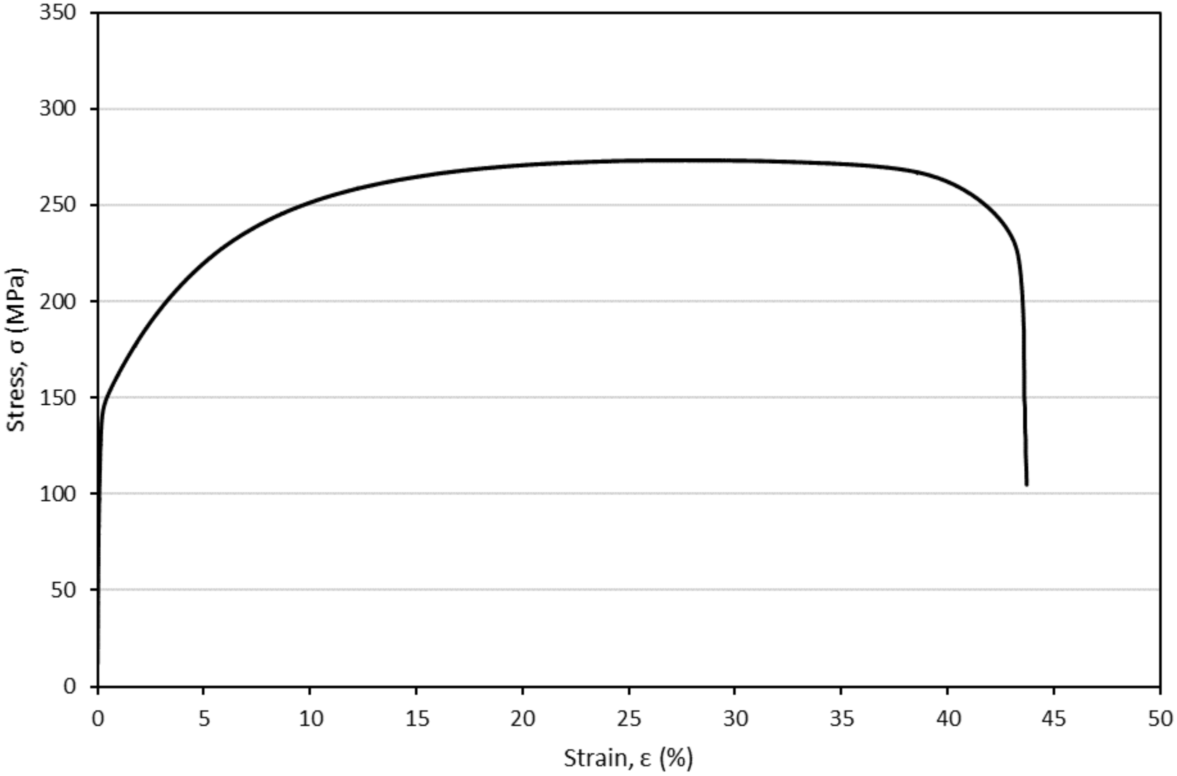


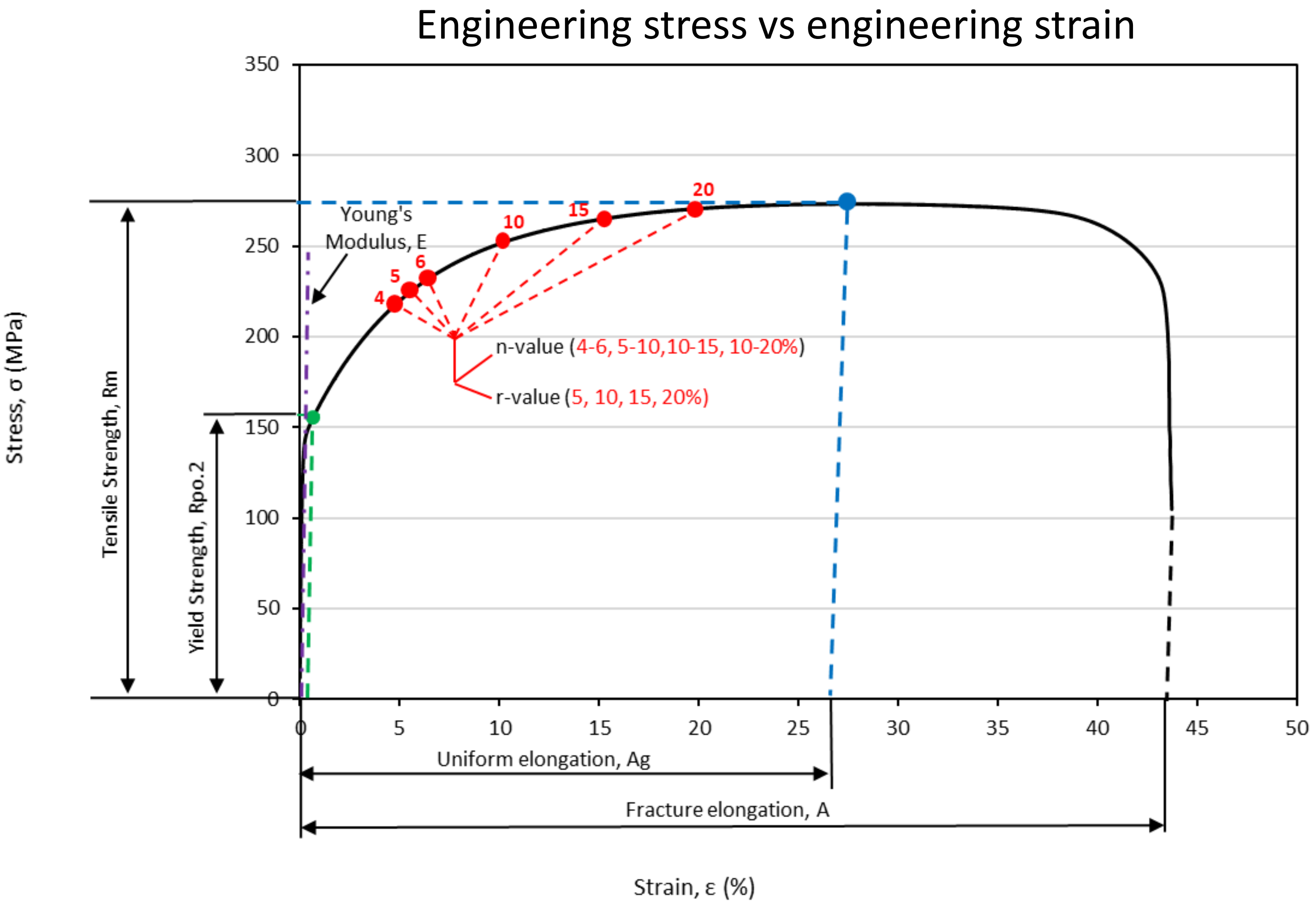
Figure 4*: Testing equipment/apparatus for tensile testing: a) Consists of a tensile machine, video extensometer, and a transverse mechanical clip-on; b) Video extensometer image with longitudinal and transverse strain.*

Data Acquisition

Engineering stress vs engineering strain



Data Acquisition



r-value

- Lankford coefficient (r-value) used to measure the formability/drawability
  - Plastic anisotropy, r-value:

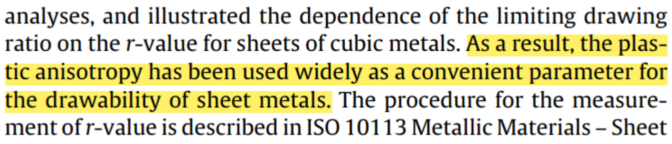
$$r = -\frac{e_{w,True}}{e_{w,True} + e_{l,True}}$$

$$\boldsymbol{r_{0,45,90} = -\frac{ln\left(1 + e_{w,Eng}\right)}{ln\left(1 + e_{w,Eng}\right) + ln\left(1 + e_{l,Eng}\right)}}$$

  - Normal anisotropy $\bar{r}$-value:

$$\boldsymbol{\bar{r} = \frac{1}{4}\left(r_0 + 2 \cdot r_{45} + r_{90}\right)}$$

Y. G. An, H. Vegter, S. Melzer and R. T. P, "**Evolution of the plastic anisotropy with straining and its implication on formability for sheet metals**" Journal of Materials Processing Technology, no. 213, pp. 1419-1425, 2013.



analyses, and illustrated the dependence of the limiting drawing ratio on the *r*-value for sheets of cubic metals. As a result, the plastic anisotropy has been used widely as a convenient parameter for the drawability of sheet metals. The procedure for the measurement of *r*-value is described in ISO 10113 Metallic Materials – Sheet

---

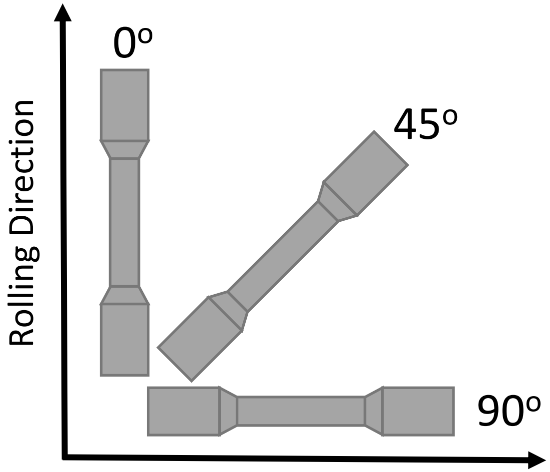


***Figure 5**: Illustration of the angle of which the tensile bars are cut for the purpose of measuring the r-value*

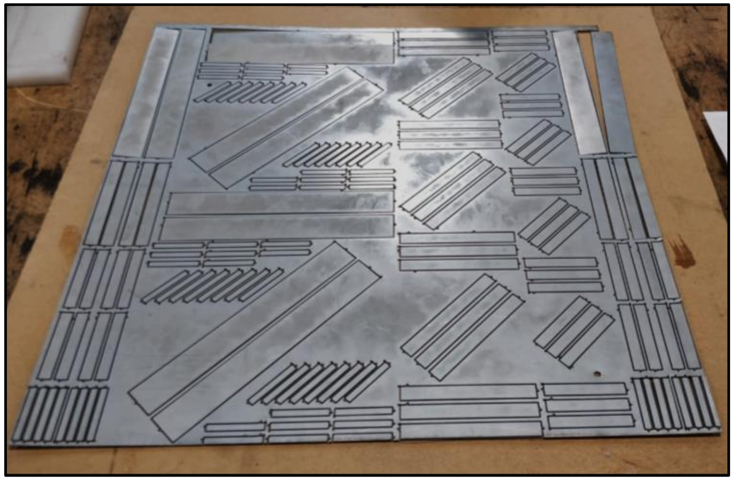
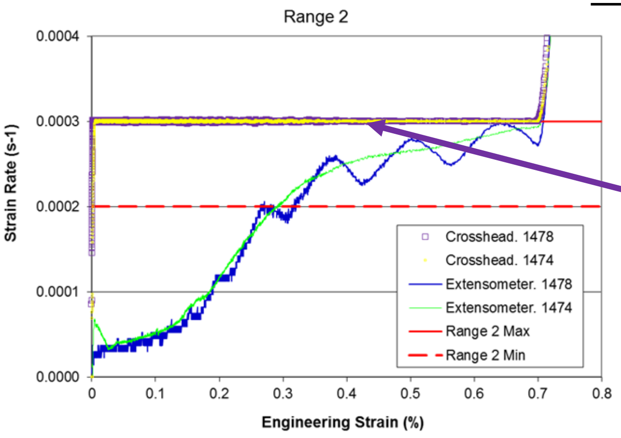
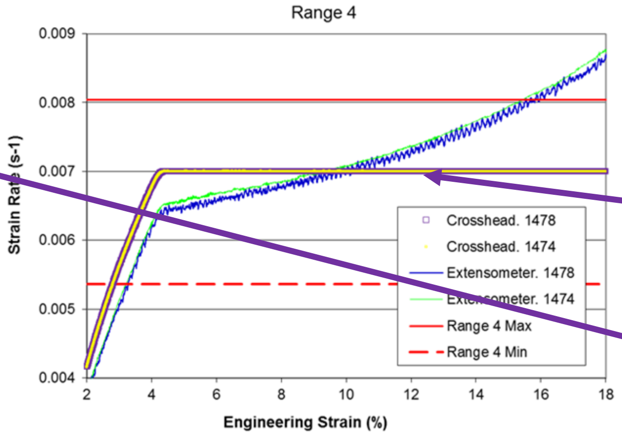


***Figure 6**: Rectangular blocks of the A80, A50, ASTM 25, Mini1, and Mini 2 waterjet out from a 500x500x0.8 mm DX57 sheet.*

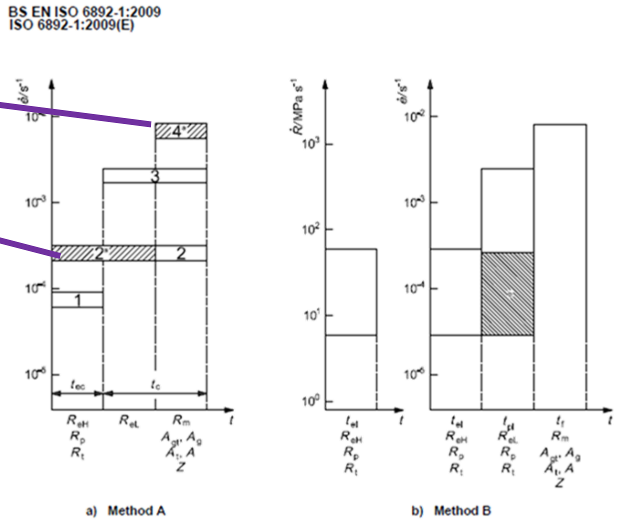
ISO Standard Strain rates

Tata





ISO 6892-1:2009 [Strain rate]


BS EN ISO 6892-1:2009
ISO 6892-1:2009(E)

a) Method A

b) Method B

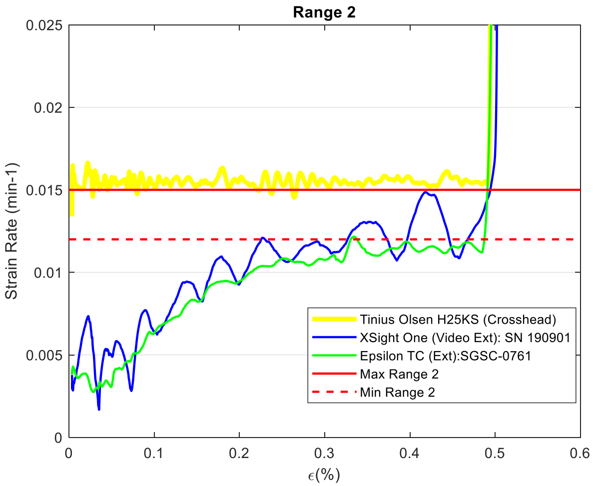
range 1: $\dot{e} = 0{,}000\,07\ s^{-1}$, with a relative tolerance of ±20 %

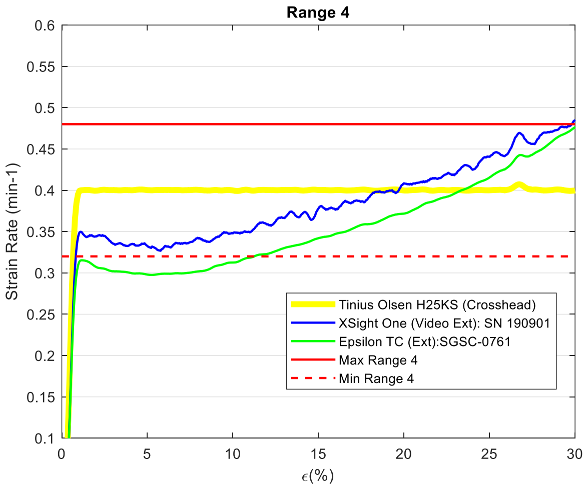
range 2: $\dot{e} = 0{,}000\,25\ s^{-1}$, with a relative tolerance of ±20 %

range 3: $\dot{e} = 0{,}002\ s^{-1}$, with a relative tolerance of ±20 %

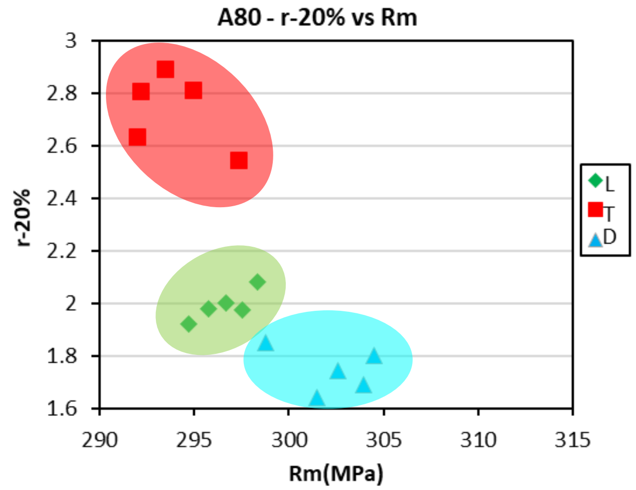
range 4: $\dot{e} = 0{,}006\,7\ s^{-1}$, with a relative tolerance of ±20 % (

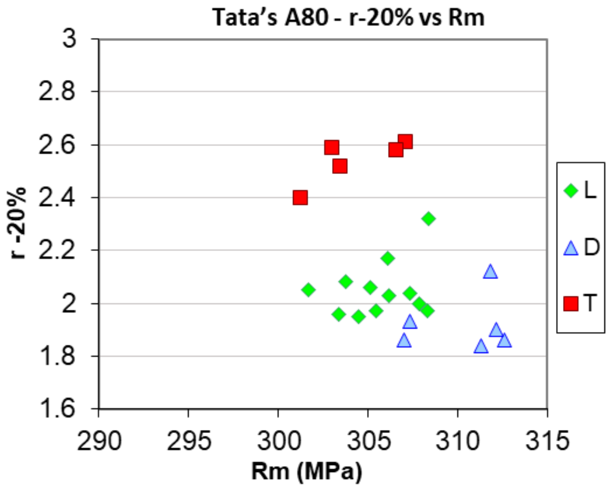
Mach 1

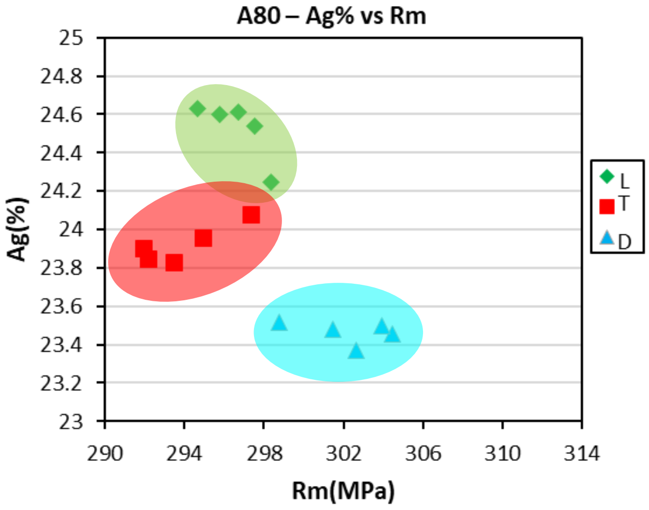


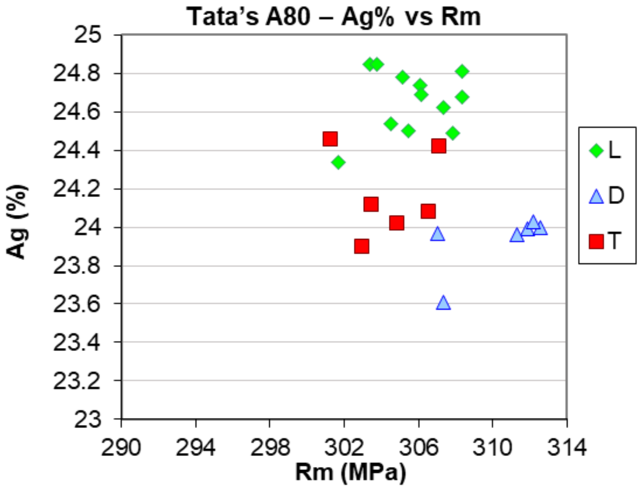


A80 data comparison – Mach 1 vs Tata

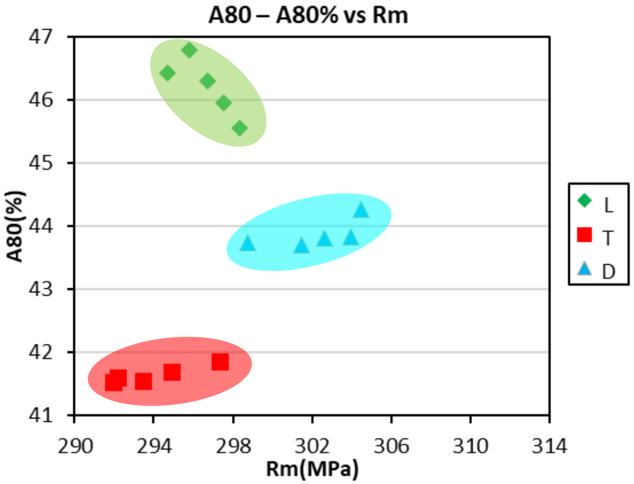

A80 - r-20% vs Rm

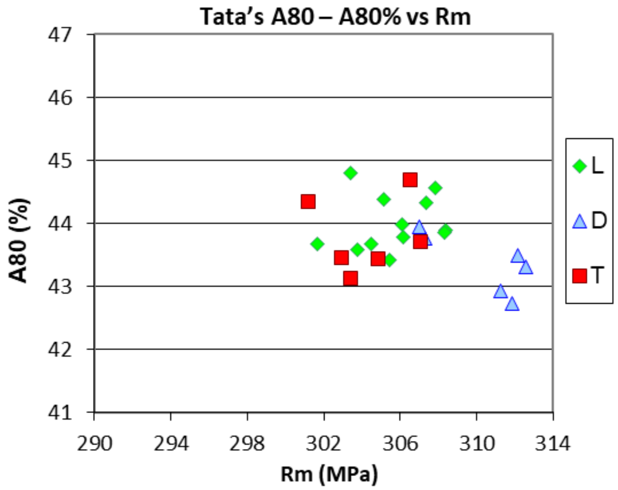

Tata's A80 - r-20% vs Rm

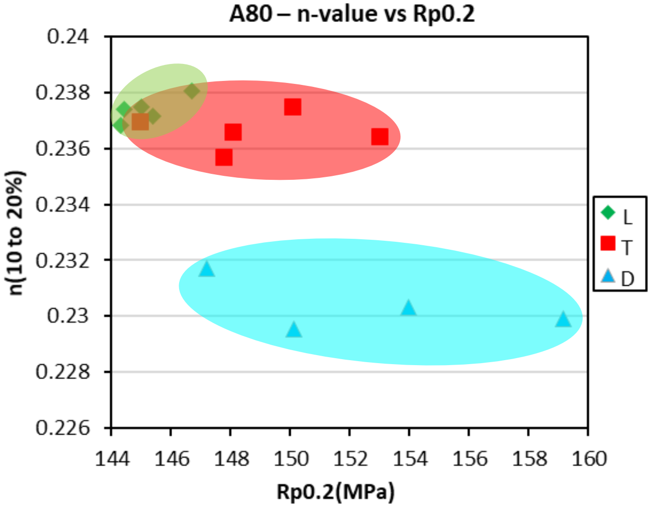

A80 – Ag% vs Rm

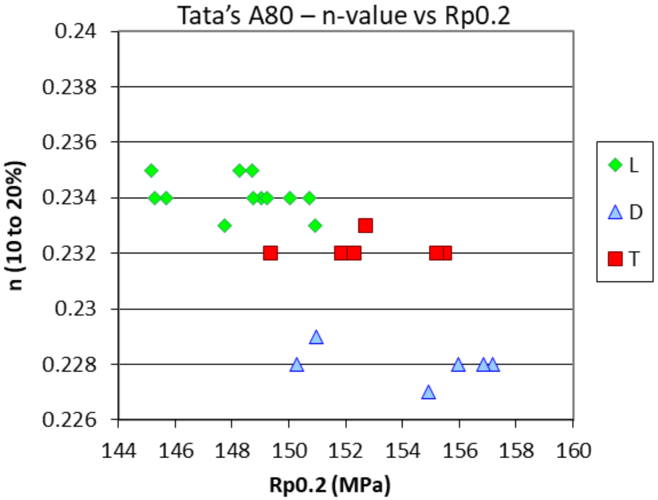

Tata's A80 – Ag% vs Rm

A80 data comparison – Mach 1 vs Tata

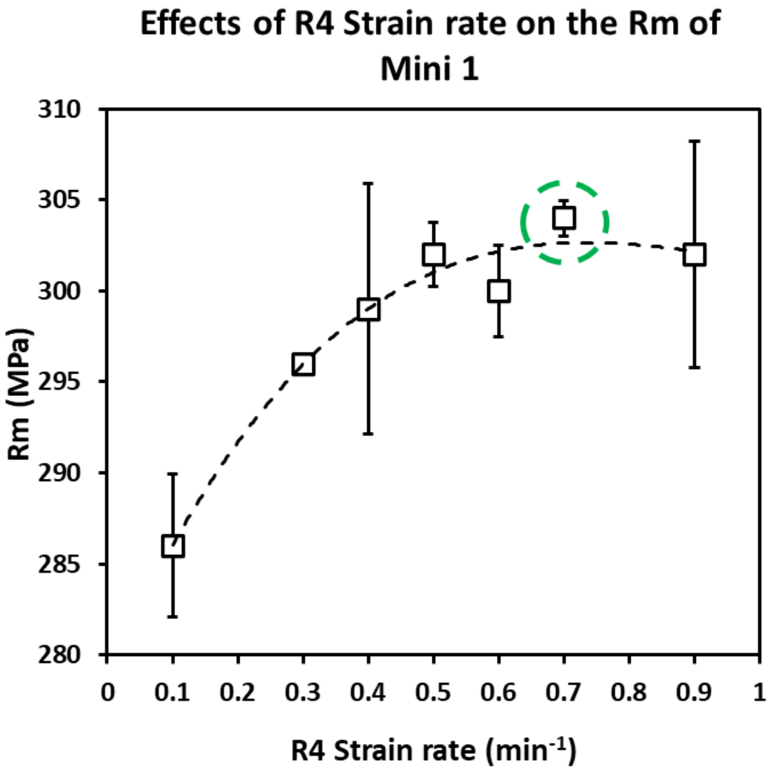

A80 – A80% vs Rm

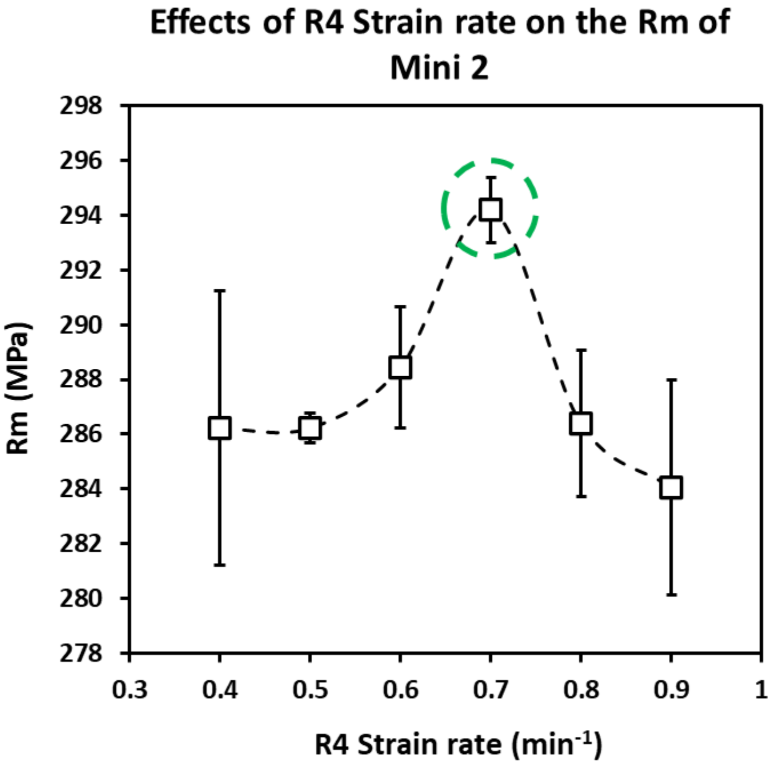

Tata's A80 – A80% vs Rm


A80 – n-value vs Rp0.2


Tata's A80 – n-value vs Rp0.2

Purpose of the project?



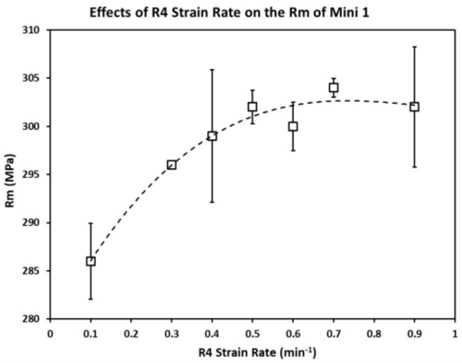


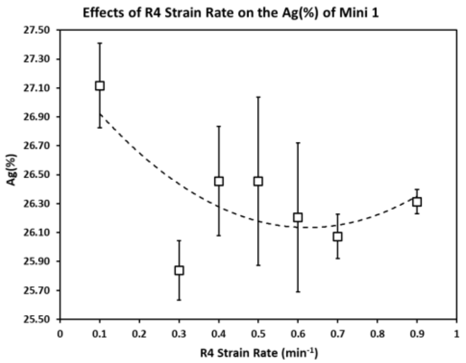
***ASTM E8/E8M – 09**: Standard Test Methods for Tension Testing of Metallic Materials*

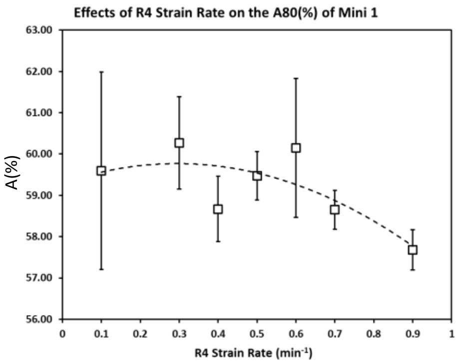
X1.4.6 Changes in the strain rate can affect the yield strength, tensile strength, and elongation values, especially for materials which are highly strain rate sensitive. In general, the yield strength and tensile strength will increase with increasing strain rate, although the effect on tensile strength is generally less pronounced. Elongation values generally decrease as the strain rate increases.

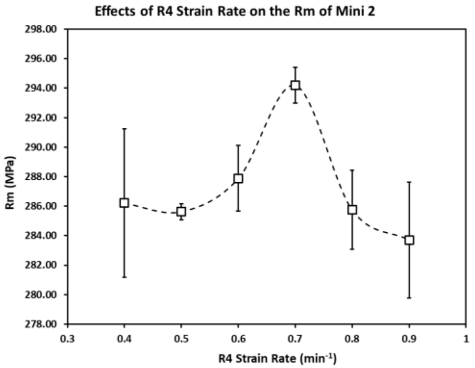
Optimum range 4 strain rate for both Mini 1 and Mini 2 is 0.7 min^{-1}

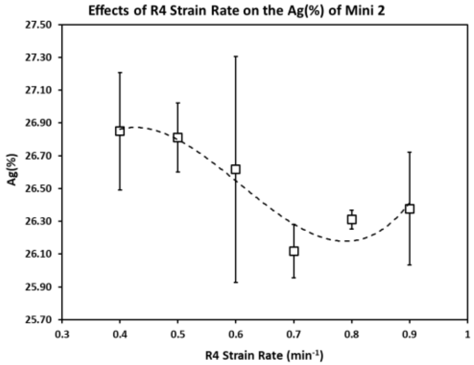
Mini 1 & Mini 2 strain rate study

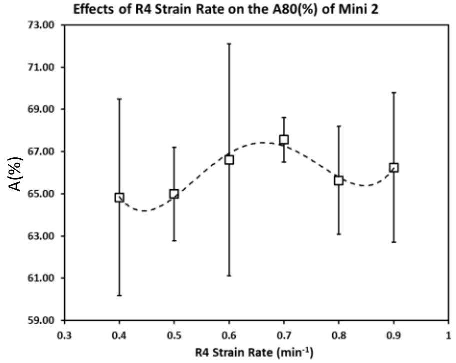

Effects of R4 Strain Rate on the Rm of Mini 1


Effects of R4 Strain Rate on the Ag(%) of Mini 1


Effects of R4 Strain Rate on the A80(%) of Mini 1

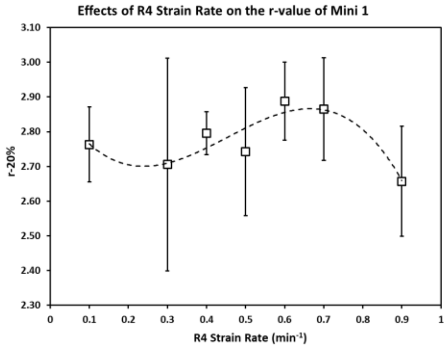

Effects of R4 Strain Rate on the Rm of Mini 2

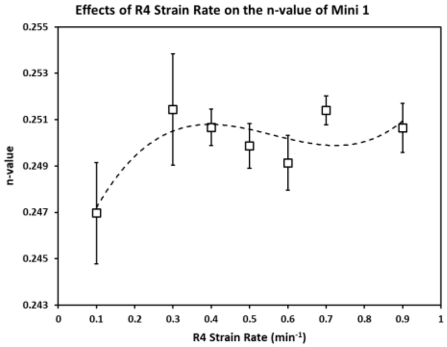

Effects of R4 Strain Rate on the Ag(%) of Mini 2

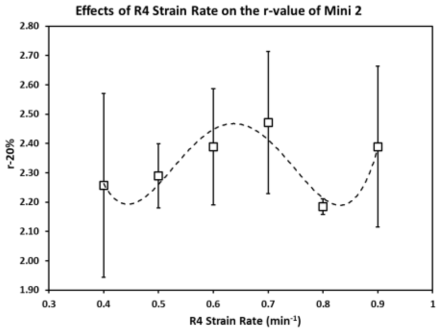

Effects of R4 Strain Rate on the A80(%) of Mini 2

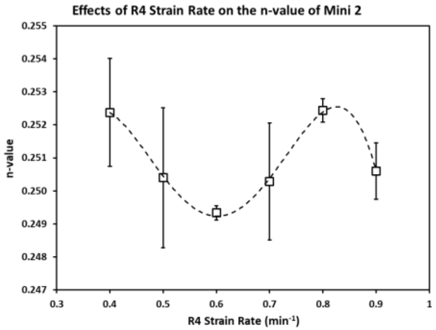
Should decrease with increase in strain rate?

No clear effects of strain rate on the r-value and n-value

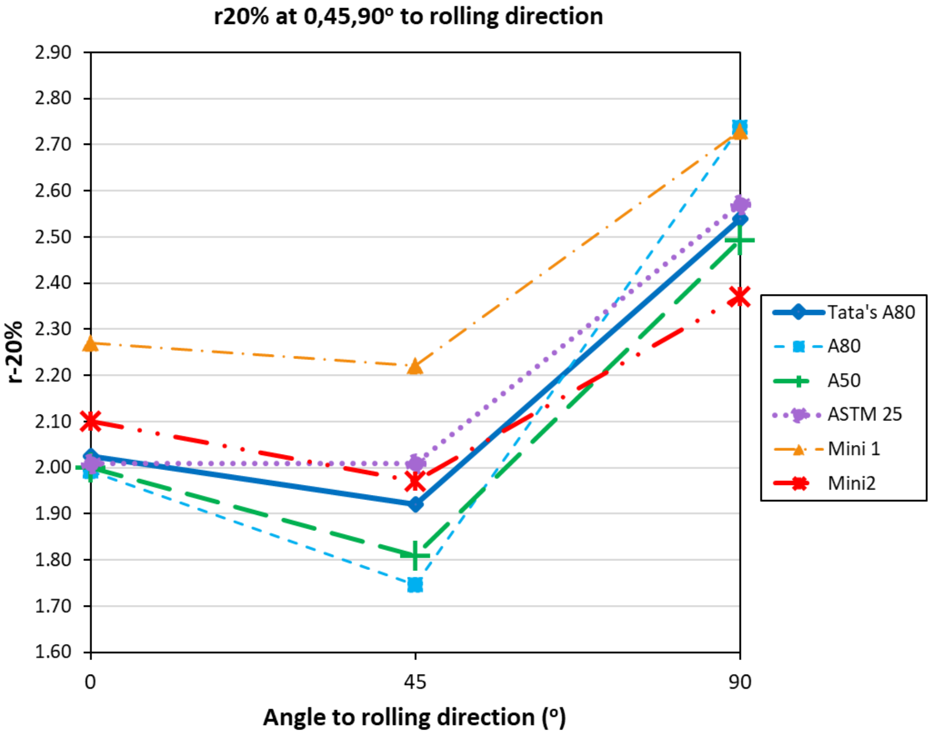

Effects of R4 Strain Rate on the r-value of Mini 1

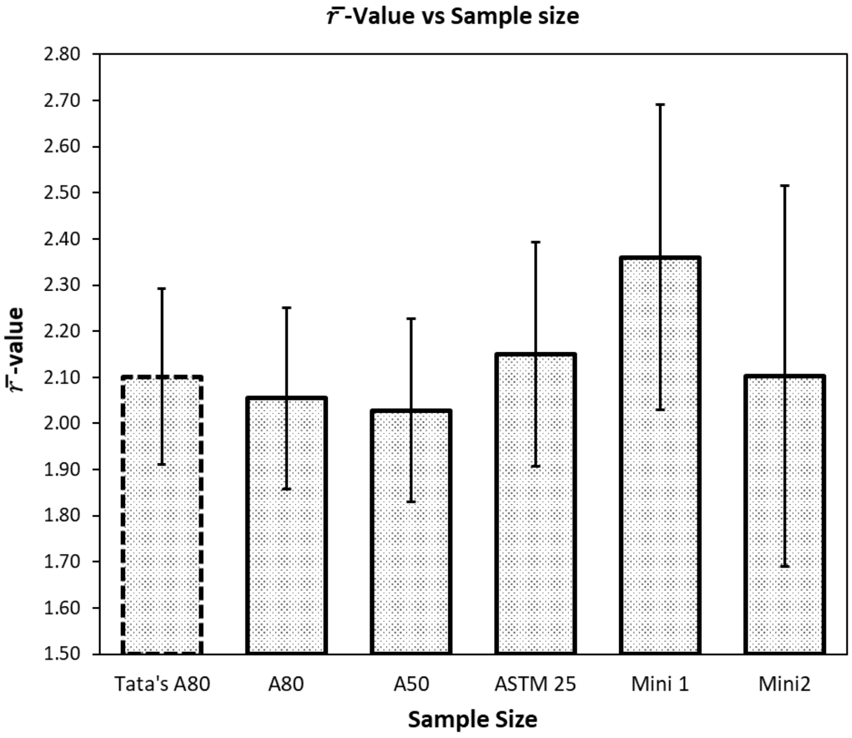

Effects of R4 Strain Rate on the n-value of Mini 1


Effects of R4 Strain Rate on the r-value of Mini 2


Effects of R4 Strain Rate on the n-value of Mini 2

Comparative scaling study of the DX57 r-value





- The r-value trend is followed in all specimen sizes
- Mini 1 appears to sit further above the rest
- As sample size decreases the uncertainty of the results increases from A50
- Mini 2 gives the most representable results but why does it appear to not follow the trend of its former specimens?

Grain Size dimensional Impact

- Grain size has an impact on the mechanical properties
- Sufficient thickness is paramount to represent the material’s polycrystalline behaviour:

$$\frac{t_0}{d_{0,average}} = \frac{0.8 \times 10^{-3}}{35 \times 10^{-6}} = \mathbf{23}$$

[K. Kumar et al. *“Optimisation of thickness of miniature tensile specimens for evaluation of mechanical properties”*. Materials Science & Engineering A 675 (2016) 32–43.]

a. YS, UTS and uniform elongation data almost stabilised corresponding to t_0/d_0 1.5 – 16
b. Also, for n-value: t_0/d_0 1.2 - 11
c. For thinner specimens, this resistance to deformation ceases faster due to the fail by voids formation and their coalescence

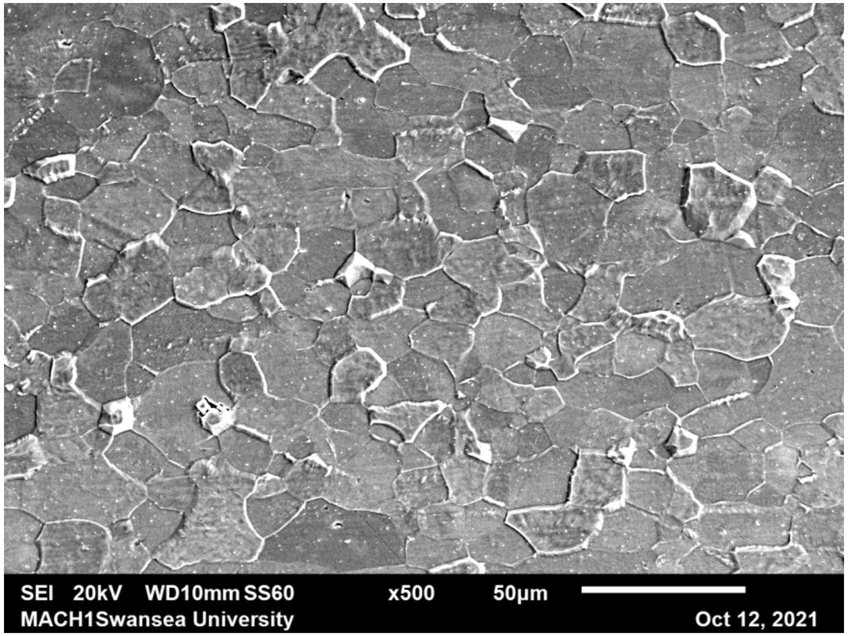


Figure 7: *SEM image of the DX57 ferritic microstructure on the cross-section. Image shows grain size (d_0) ranging from 20µm- 50µm.*

Figure 8: *Side view of a tensile specimen, illustrating its thickness.*

Redesign of Mini 1 & Mini 2

- Increase gauge length, L_0, to acquire a 4:1 aspect ratio configuration

Table 2 *: Current dimensions of the Tensile specimens.*

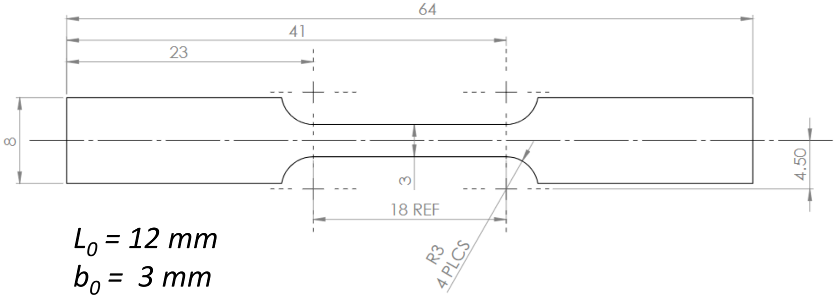
	A80	A50	ASTM 25	MINI 1	MINI 2
lc	120	75	31.53	12.5	9
lo	80	50	25	10	5
bo	20	12.5	6	3	2
Aspect Ratio(lo/bo)	4.00	4.00	4.17	3.3	2.5
Aspect Ratio(lc/bo)	6.00	6.00	5.3	4.2	4.5

- L_o/b_o to be changed to 4
- L_c/b_o seems to display an increase in ratio which opposes the L_o/b_o

[O.N. Pierron, D.A. Koss, A.T. Motta. *"Tensile specimen geometry and the constitutive behaviour of Zircaloy-4"*. Journal of Nuclear Materials 312 (2003), 257 – 276.]

a. Aspect ratio (L_0/b_0) of 4, provides the most accurate representation of the constitutive behaviour for the material Zircaloy-4
   i. 4:1 ➔ The only ratio that displayed uniform deformation at maximum load
   ii. 3:2
   iii. 1:1

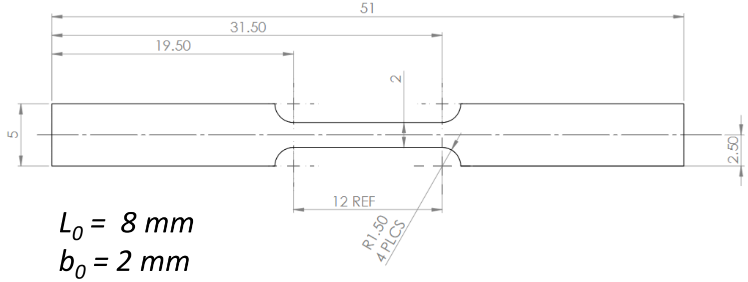
New Mini 1



L_0 = 12 mm
b_0 = 3 mm

Figure 9*: Engineering drawing of the new Mini 1 tensile specimen.*

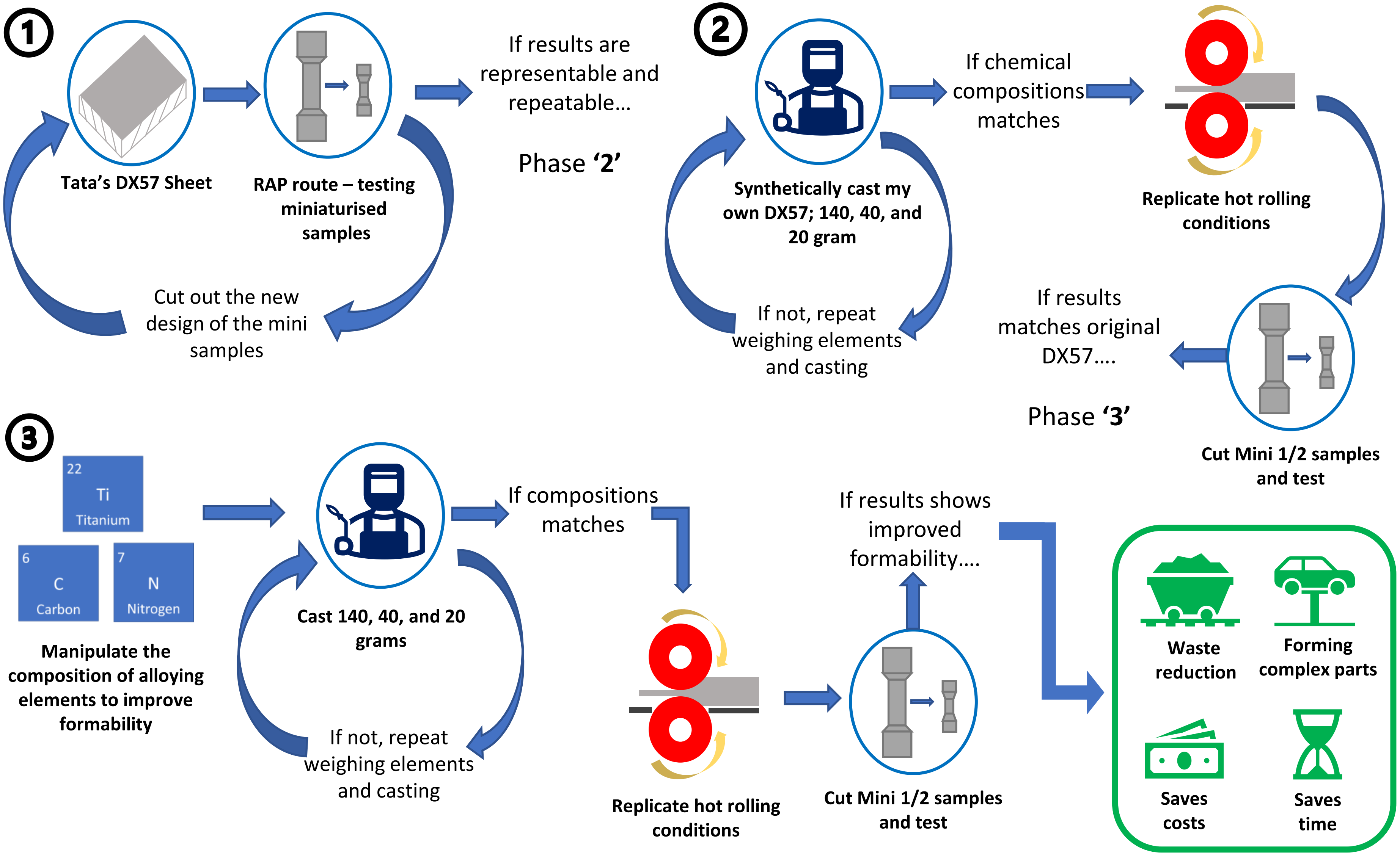
New Mini 2



L_0 = 8 mm
b_0 = 2 mm

Figure 10*: Engineering drawing of the new Mini 2 tensile specimen.*

Why is this all important?



①

Tata's DX57 Sheet

RAP route – testing miniaturised samples

Cut out the new design of the mini samples

If results are representable and repeatable…

Phase **'2'**

②

Synthetically cast my own DX57; 140, 40, and 20 gram

If not, repeat weighing elements and casting

If chemical compositions matches

Replicate hot rolling conditions

Cut Mini 1/2 samples and test

If results matches original DX57….

Phase **'3'**

③

Manipulate the composition of alloying elements to improve formability

Cast 140, 40, and 20 grams

If not, repeat weighing elements and casting

If compositions matches

Replicate hot rolling conditions

Cut Mini 1/2 samples and test

If results shows improved formability….

Waste reduction

Forming complex parts

Saves costs

Saves time

Any Questions?