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THE EFFECT OF STRAIN RATE ON TENSILE PROPERTIES AND FRACTURE STRAIN

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Outline

- Background
- Purpose of the work
- Materials tested
- Results
  - Strain rate effect on tensile properties
  - Strain rate effect on fracture strain
- Conclusions

Background

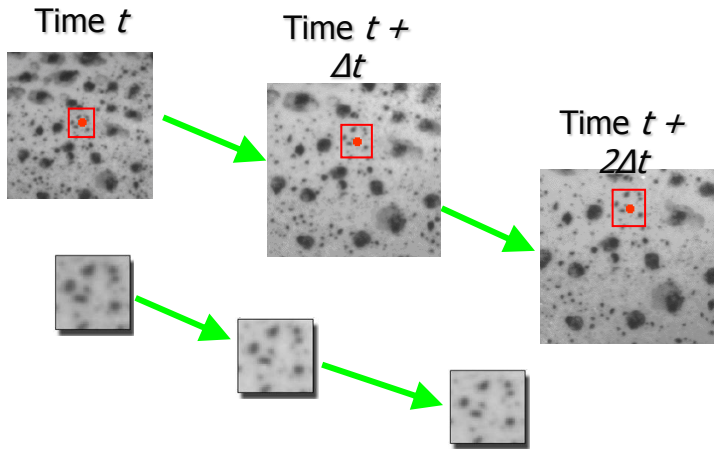
- Effect of strain rate on tensile properties and fracture behavior is of critical importance to crash performance.
- There are two major issues for tensile testing at high strain rates
  - Severe load oscillation deteriorates quality of stress-strain curve
  - Existing strain measurement devices (strain gage, LVDT, or Doppler extensometer) are not accurate and reliable at high strain rates
- Data on the effect of strain rate on tensile properties/fracture strain is scarce due to testing difficulties

Purpose of Work

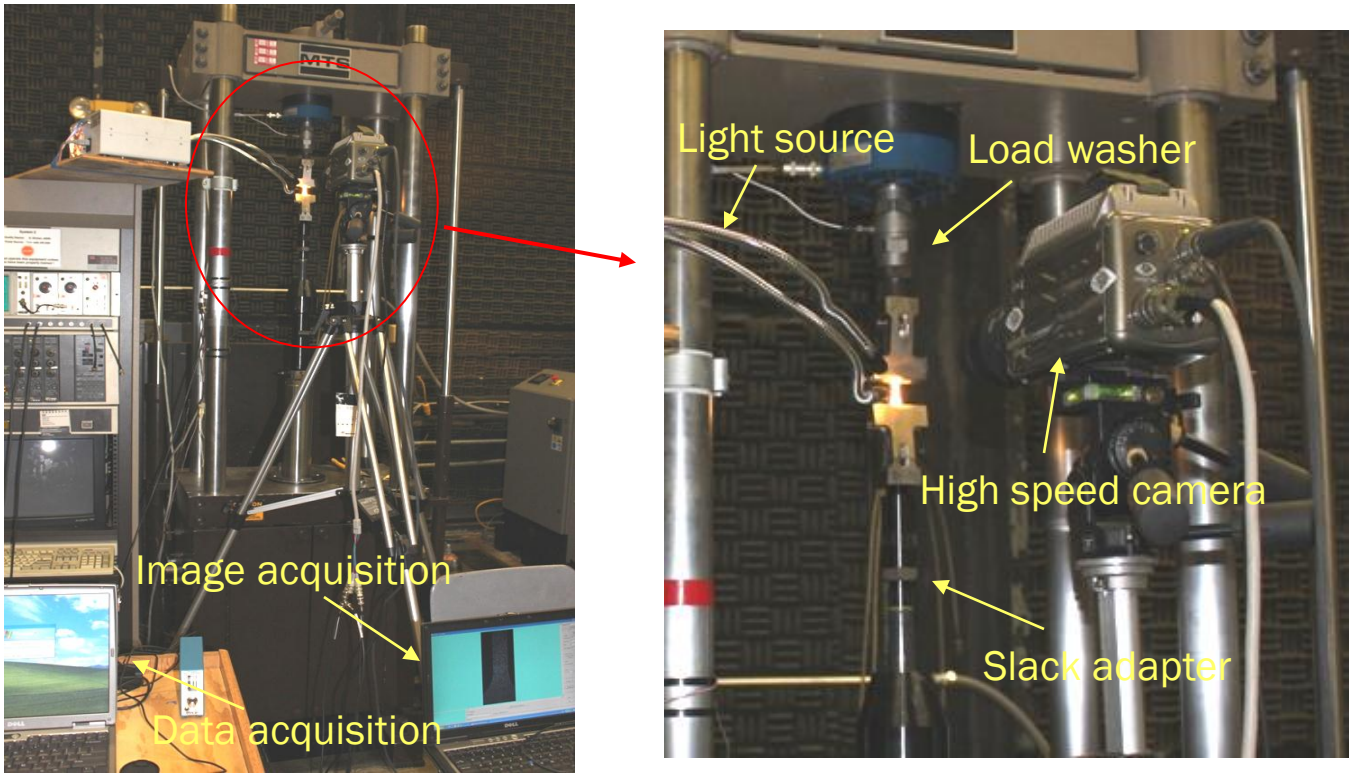
- Improve data quality of high strain rate tests by using Digital Image Correlation (DIC) technique
- Understand strain rate effect on fracture strain using DIC
  - Tensile fracture
  - Cut edge fracture

Experiment

- Tensile test at high strain rate
  - MTS servo-hydraulic testing machine
    - 20kip load capacity
    - Maximum speed 5.5 m/s
- 3-point bending of hat section beam
  - Quasi-static: 100kip MTS testing machine
  - Dynamic: drop tower mass 380 kg, speed 8m/s
- Digital Image Correlation (DIC)
  - Full field non-contact deformation measurement
  - Accurate output of displacement and strain

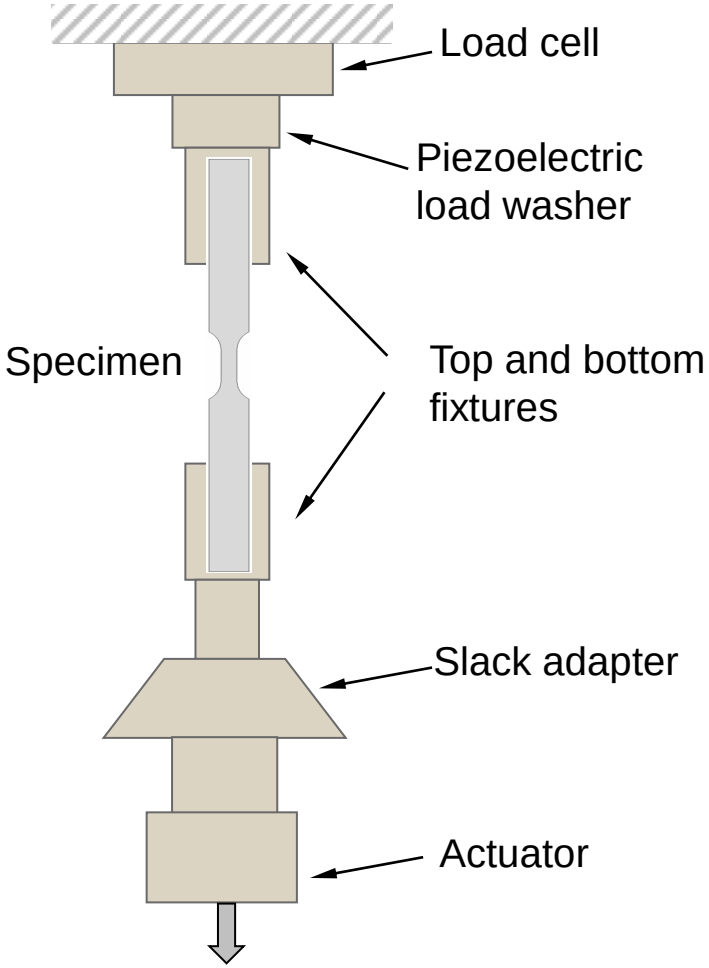


High Strain Rate Test

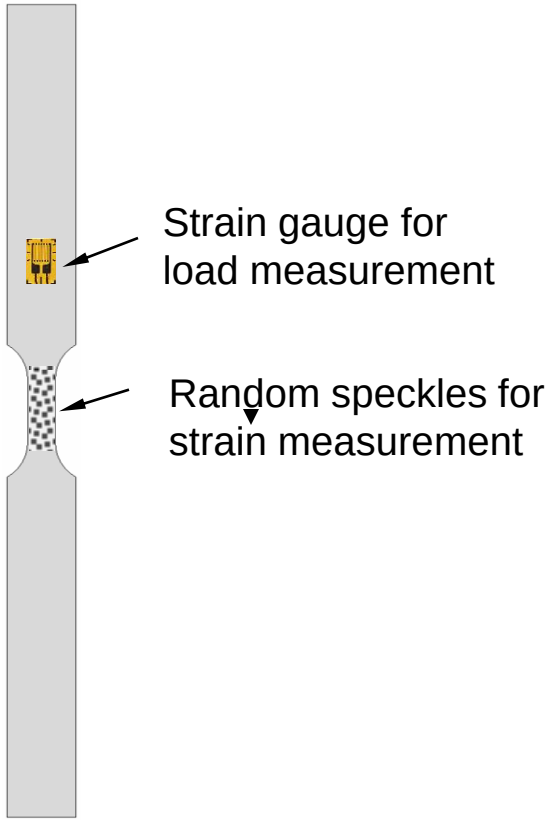


High strain rate test with DIC system

High Strain Rate Test

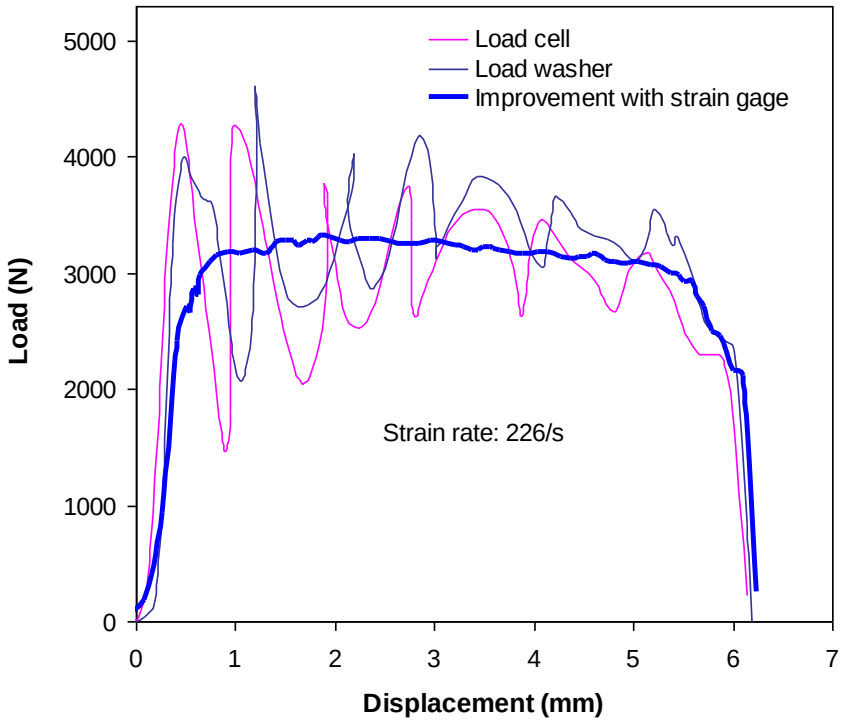


Schematic of testing setup

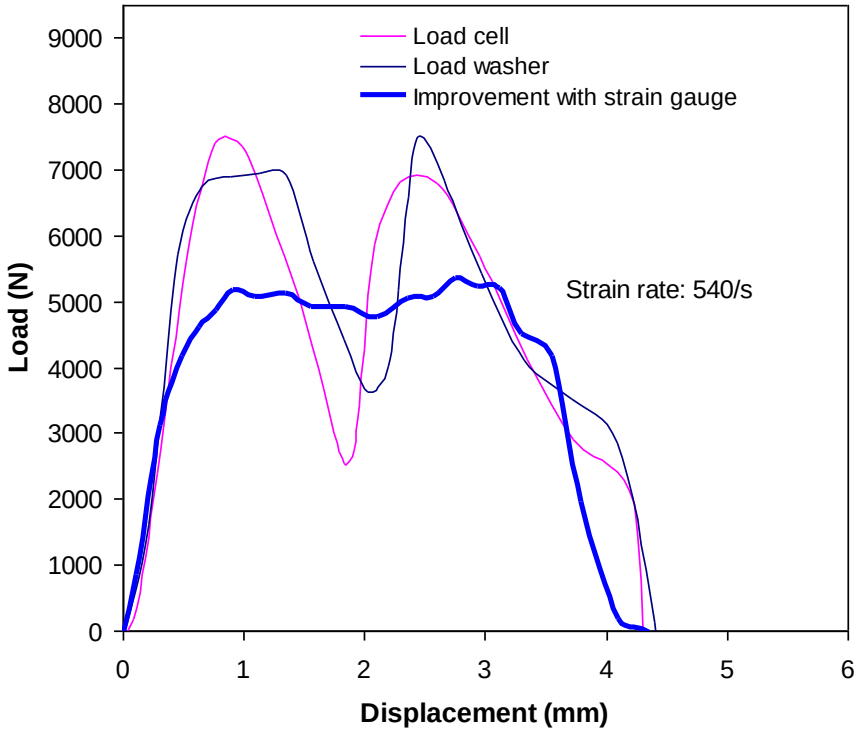


High strain rate specimen

High Strain Rate Test – Load Signal Improvement



Load-displacement curves of DP590 at 220/s



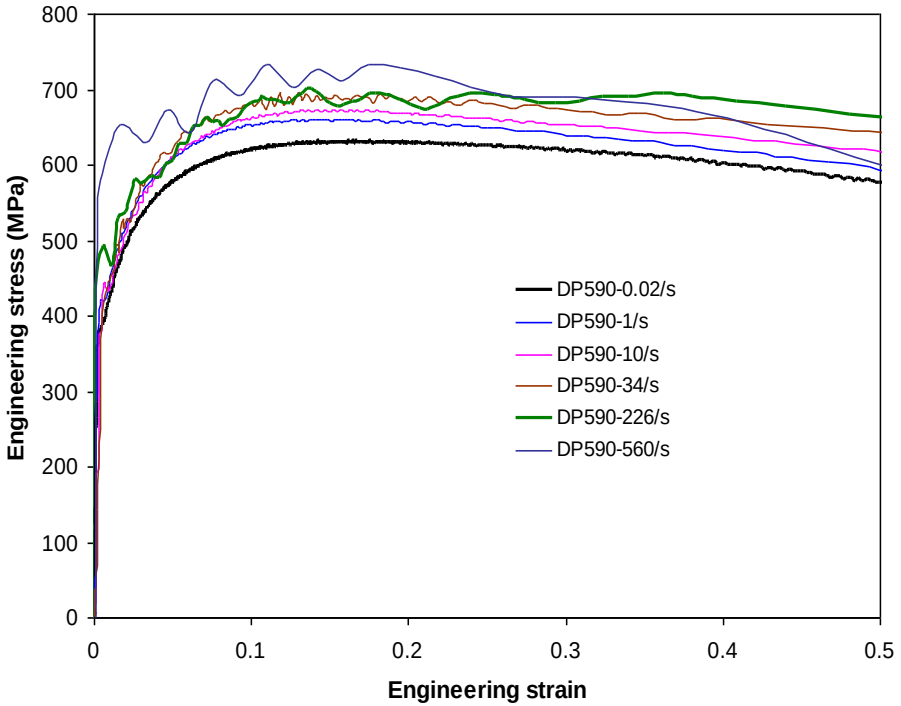
Load-displacement curves of DP780 at 550/s

Materials

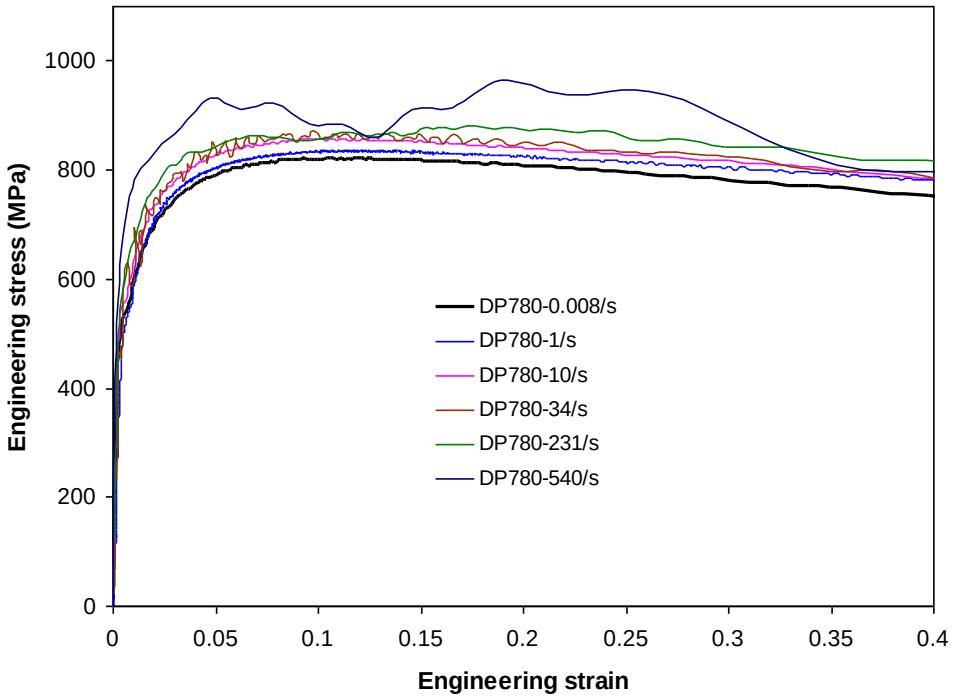
Tensile Properties

Material	Thickness (mm)	Coating	Yield Strength (MPa)	Tensile Strength (MPa)	Uniform Elongation (%)	Total Elongation (%)	Local Fracture strain (%)
EDDS	1.54	Uncoated	123	284	27.0	55.0	110
DP590 CR	1.4	Uncoated	347	612	17.0	28.0	73
590R	1.4	GA	485	618	14.3	22.1	66
DP780	1.4	EG	527	822	11.1	18.0	58
TRIP780	1.4	GA	503	892	15.0	21.3	46
DP980	1.4	Uncoated	636	1043	8.5	13.4	46
DP980	1.4	GA	645	1002	8.4	13.8	45

Stress-strain Curves

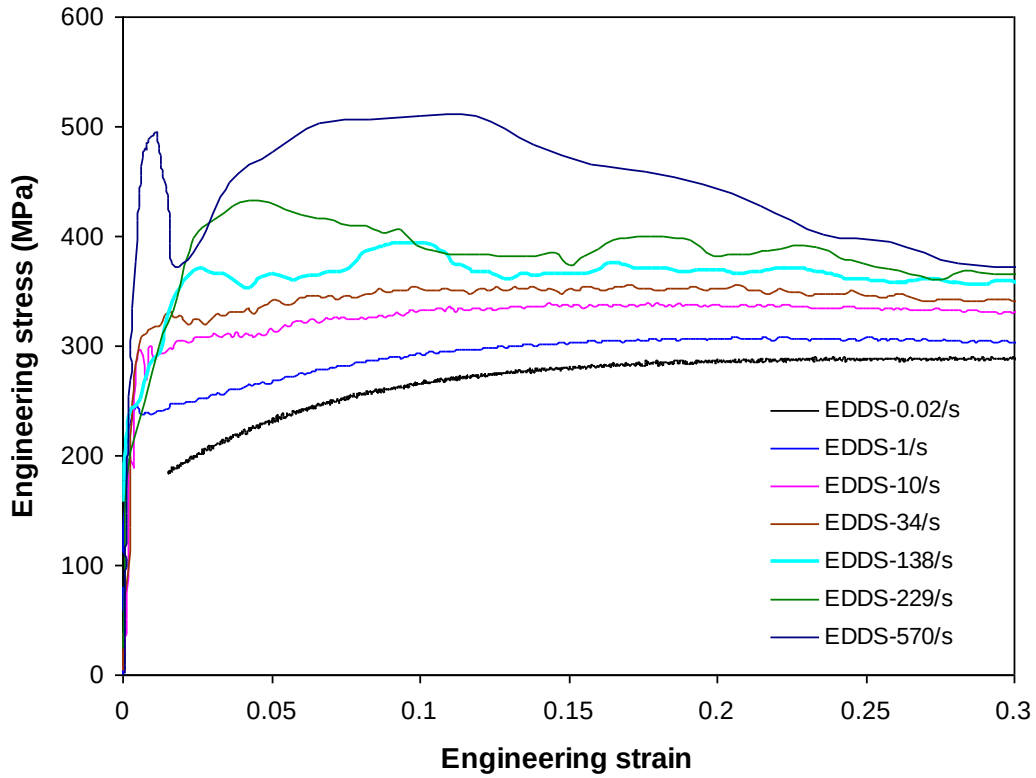


Engineering stress-strain curves of DP590



Engineering stress-strain curves of DP780

Stress-strain Curves



Engineering stress-strain curves of EDDS

Strain Rate Effect on Tensile Properties

Tensile properties of EDDS at different strain rates

Tensile properties	0.02 /s	1 /s	10 /s	34 /s	138 /s	229 /s	570 /s
UTS (MPa)	286	307	338	354	371	400	450
UE	0.271	0.251	0.2	0.214	0.233	0.217	0.195
TEL (5mm GL)	0.958	0.917	0.983	NA	0.942	0.9833	NA

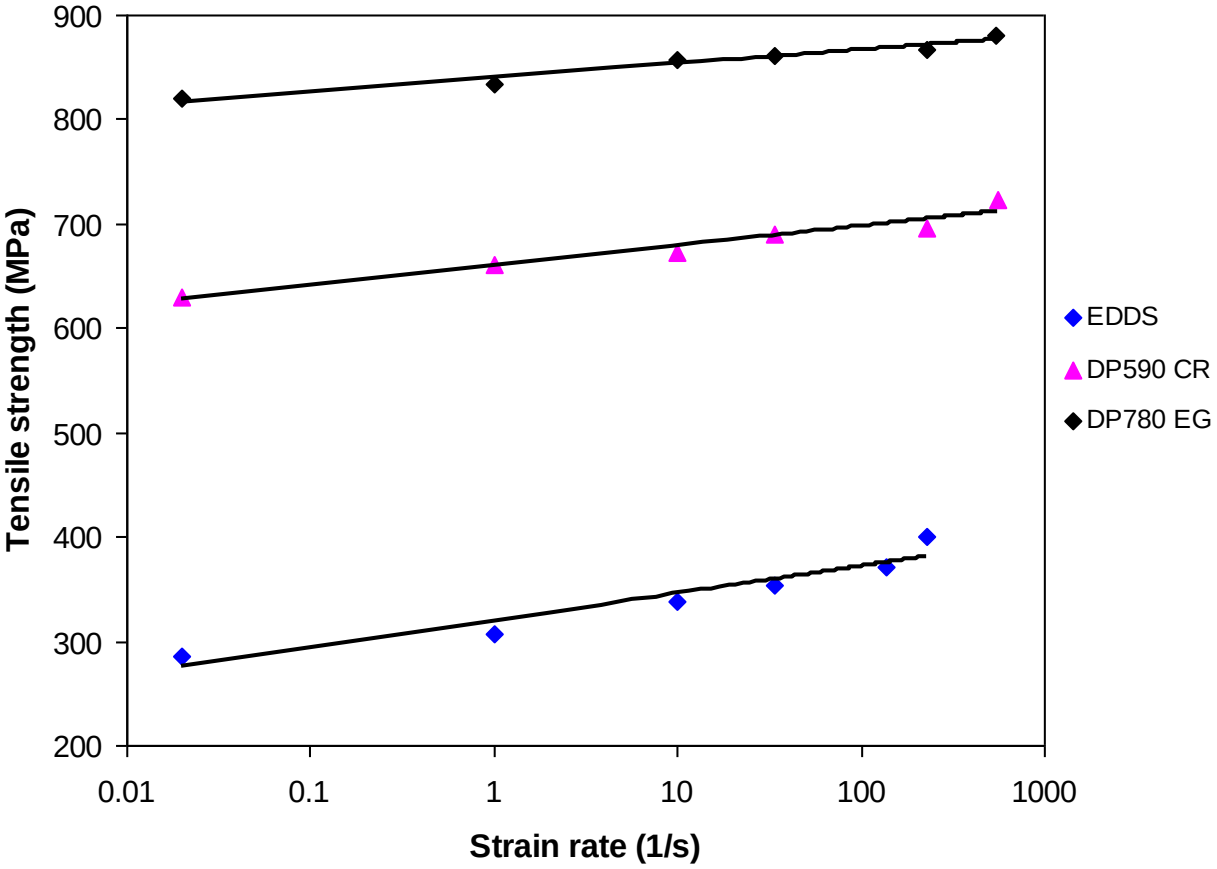
Tensile properties of DP590 at different strain rates

Tensile properties	0.02 /s	1 /s	10 /s	34 /s	226 /s	560 /s
UTS (MPa)	630	660	672	690	696	723
UE	0.17	0.168	0.175	0.169	0.175	0.174
TEL (5mm GL)	0.547	0.467	0.517	0.55	0.517	0.533

Tensile properties of DP780 at different strain rates

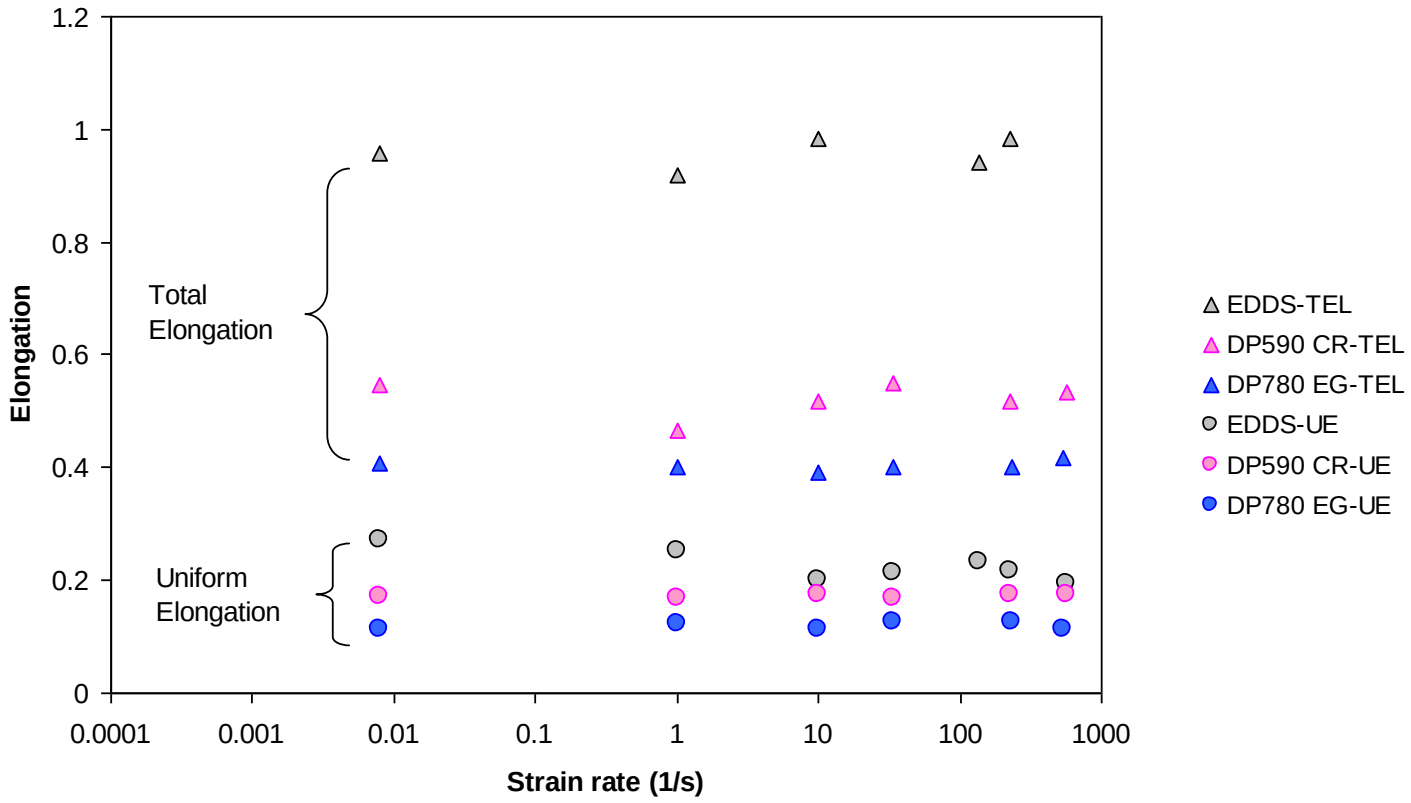
Tensile properties	0.02 /s	1 /s	10 /s	34 /s	231 /s	540 /s
UTS (MPa)	820	833	857	862	867	880
UE	0.114	0.124	0.112	0.125	0.126	0.112
TEL (5mm GL)	0.408	0.4	0.392	0.4	0.4	0.417

Strain Rate Effect on Tensile Strength



Relation between tensile strength and strain rate

Strain Rate Effect on Elongations



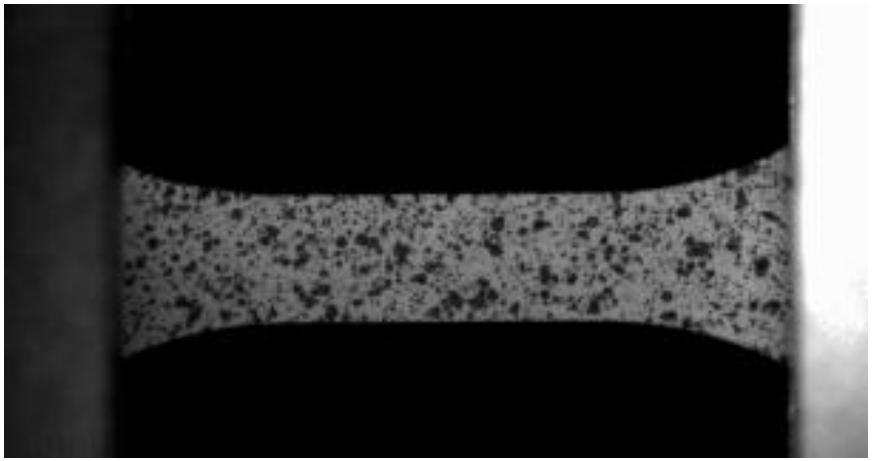
Uniform elongation and total elongation with respect to strain rate

Strain Rate Effect on tensile fracture strain

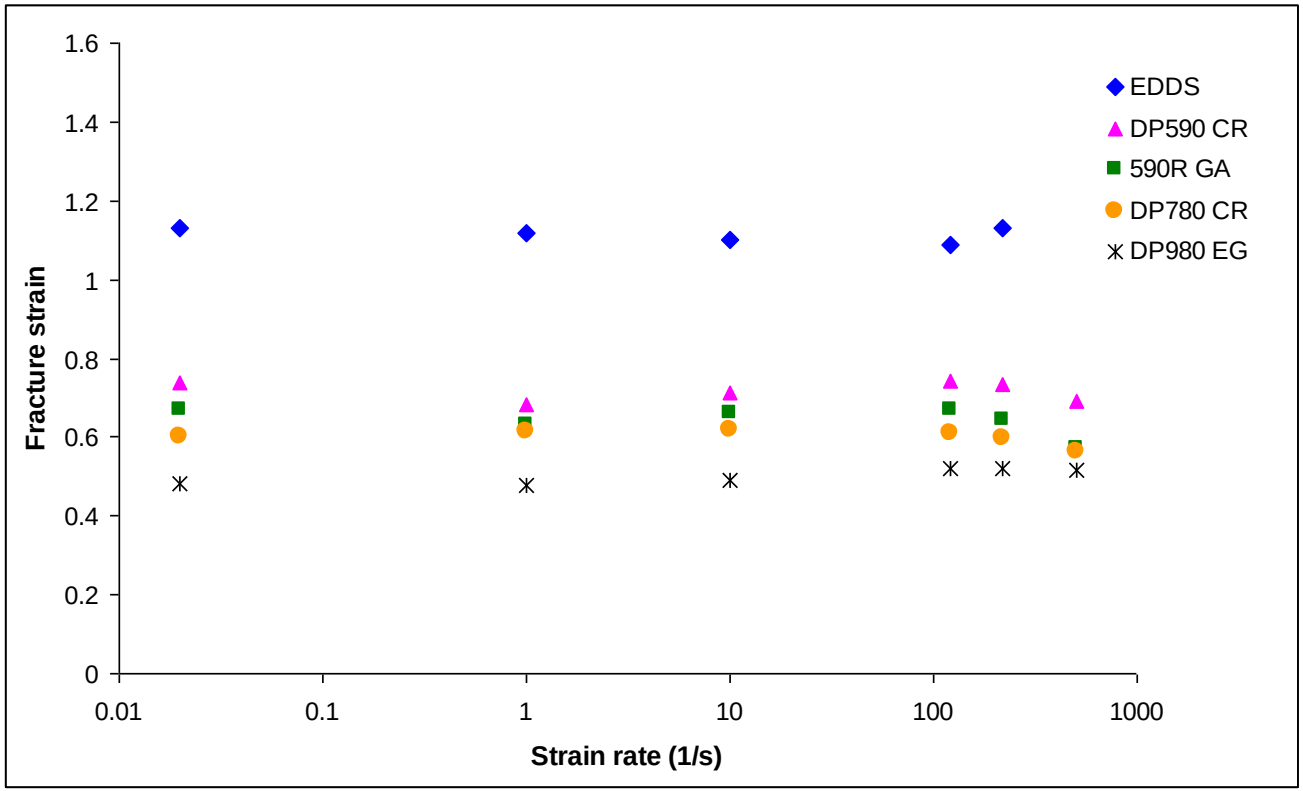
Fracture strain of 5 materials at different strain rates

Material	Quasi – static	1/s	10/s	120/s	220/s	500/s	Standard deviation
EDDS	1.13	1.12	1.1	1.09	1.13	NA	0.018
DP590 CR	0.738	0.681	0.711	0.741	0.734	0.691	0.025
GA 590R	0.668	0.6295	0.661	0.6715	0.6446	0.5718	0.037
DP780	0.602	0.615	0.619	0.611	0.598	0.564	0.02
DP980 LC	0.4819	0.4762	0.4908	0.5202	0.5193	0.5174	0.02

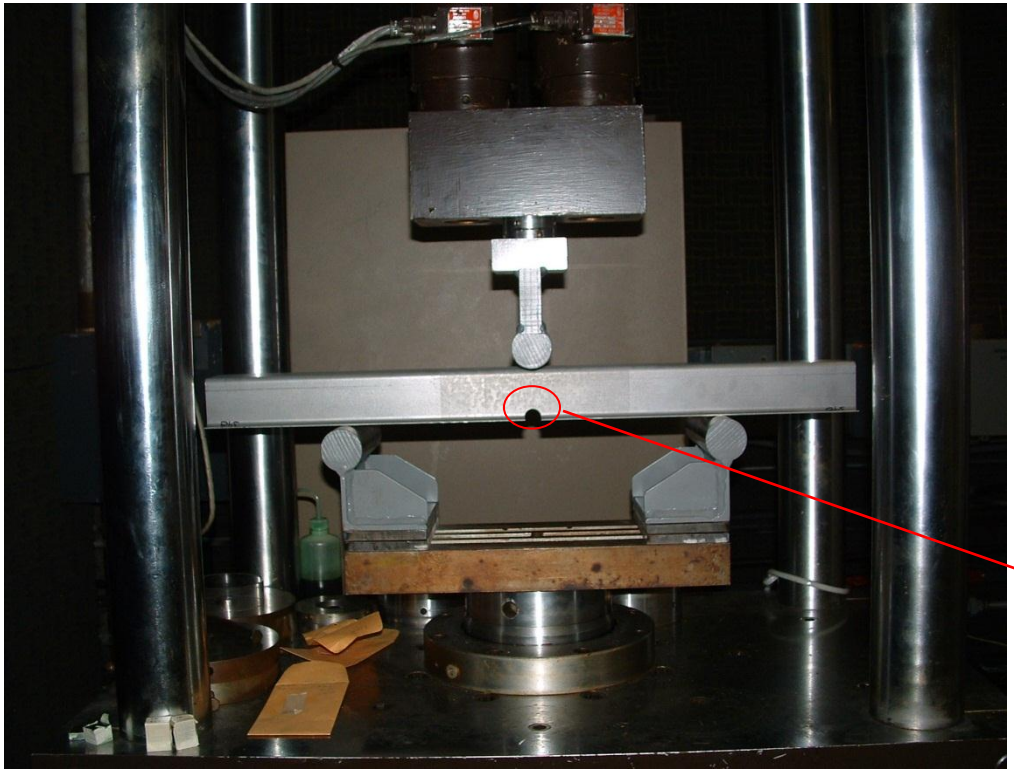
An animation showing the speckles change of GA 590R at 200/s (camera speed 4000 frame/s)

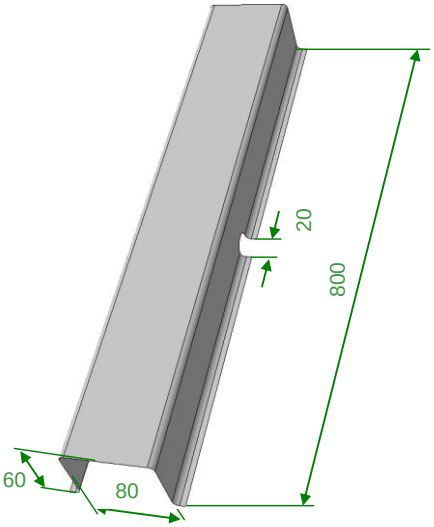


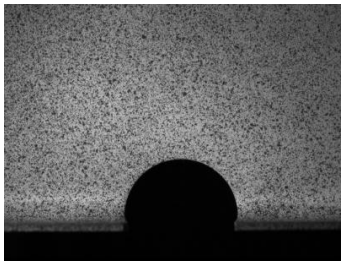
Strain Rate Effect on fracture strain



3-point Bending Beam Tests – Quasi-static

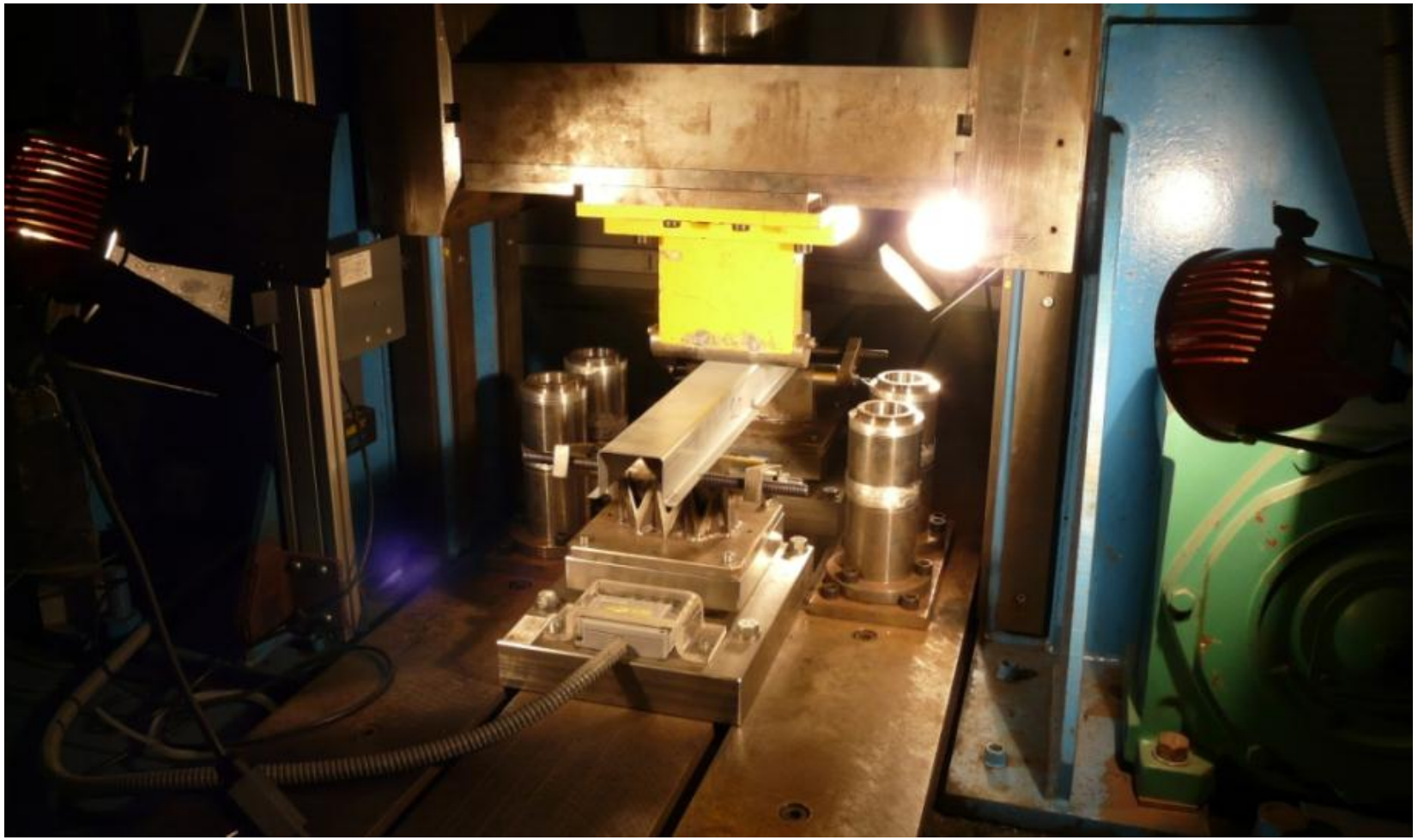






Test setup of quasi-static beam test and specimen

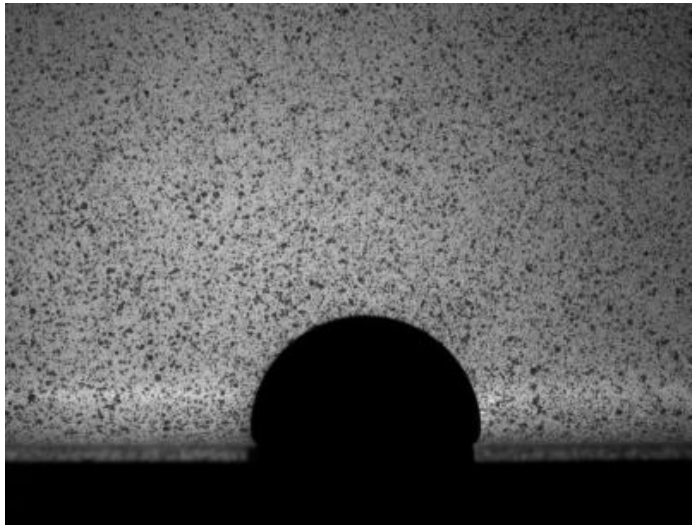
3-point Bending Beam Tests – Dynamic



Strain Rate Effect on Edge fracture strain

Material	Edge Fracture Strain			
	Notch from water-jet cutting		Notch from punching	
	Beam-dynamic* (~ 65/s)	Beam- quasi-static (~ 0.46/s)	Beam- dynamic* (~ 65/s)	Beam- quasi-static (~ 0.46/s)
DP980 CR	0.35	0.39	0.36	0.34
DP980 GA	0.28	0.32	0.3	0.29
TRIP 780 GA	0.38	0.37	0.27	0.2
GA 590R	0.45	0.57	0.45	0.5

*Note: The fracture strain of dynamic beam was determined using FEA combined with experiment (fracture strain of quasi-static beam was directly measured using DIC)



Conclusions

- Data quality of high strain rate testing is improved by applying strain gauge in grip section and DIC technique.
- Strain rate has little effect on uniform elongation and total elongation for Advanced High Strength Steels (AHSS) such as DP590 and DP780.
- In agreement with existing data, the tensile strength increases with strain rate.
- Strain rate exhibited insignificant effect on fracture strain for the tested materials.
- DIC can be used as an effective tool in strain measurement for plasticity and fracture studies for high strength steels.