



ArcelorMittal

THE EFFECT OF STRAIN RATE ON TENSILE PROPERTIES AND FRACTURE STRAIN

Gang Huang, Benda Yan and Hong Zhu
ArcelorMittal USA LLC





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

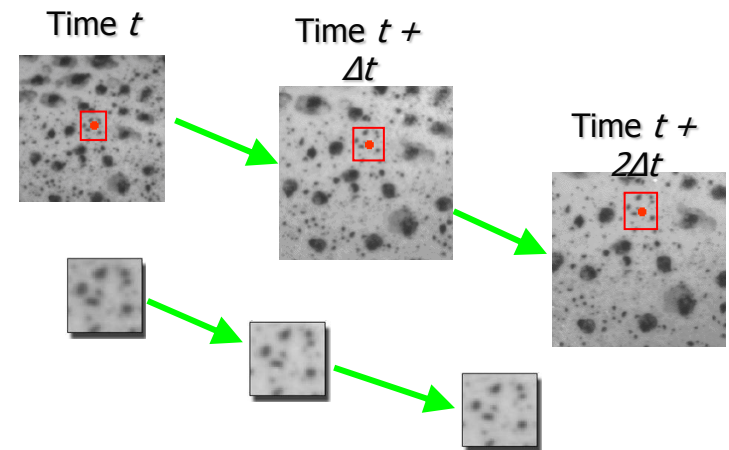
- Improve data quality of high strain rate tests by using Digital Image Correlation (DIC) technique
- Understand strain rate effect on fracture strain using DIC
 - Tensile fracture
 - Cut edge fracture





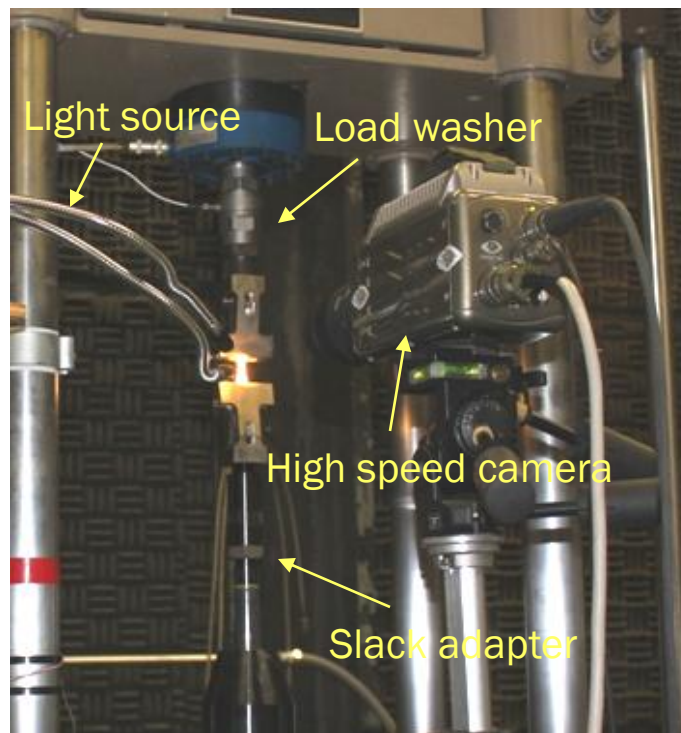
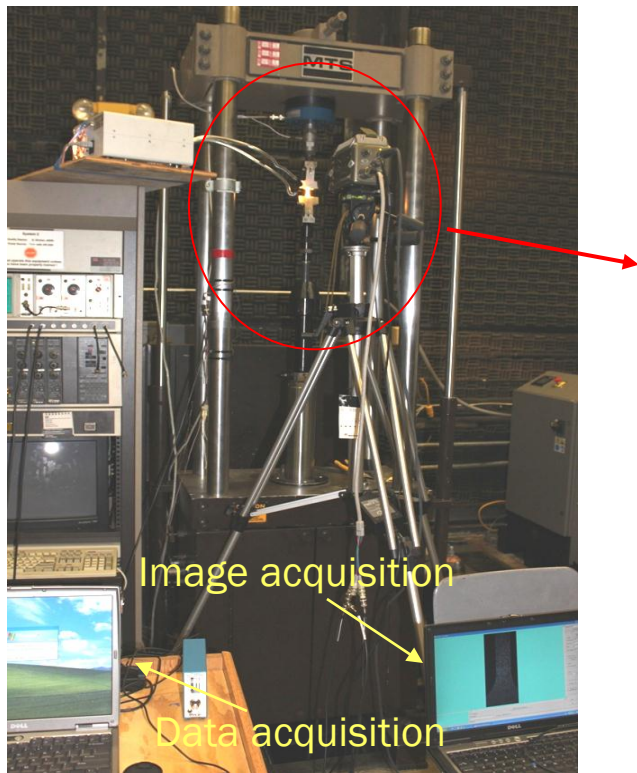
Experiment

- 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





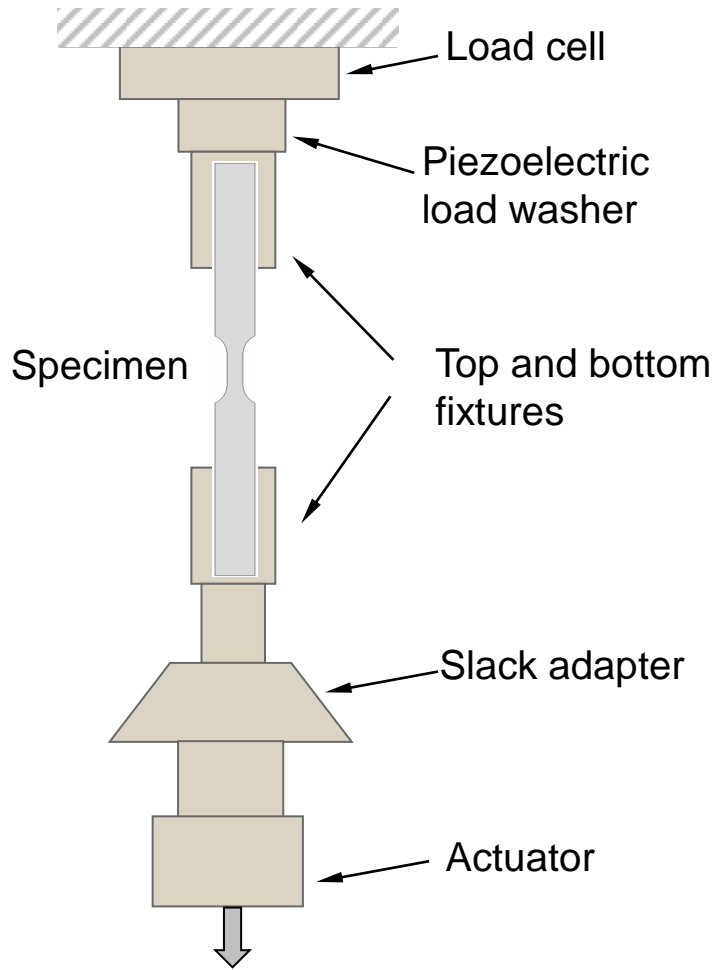
High Strain Rate Test



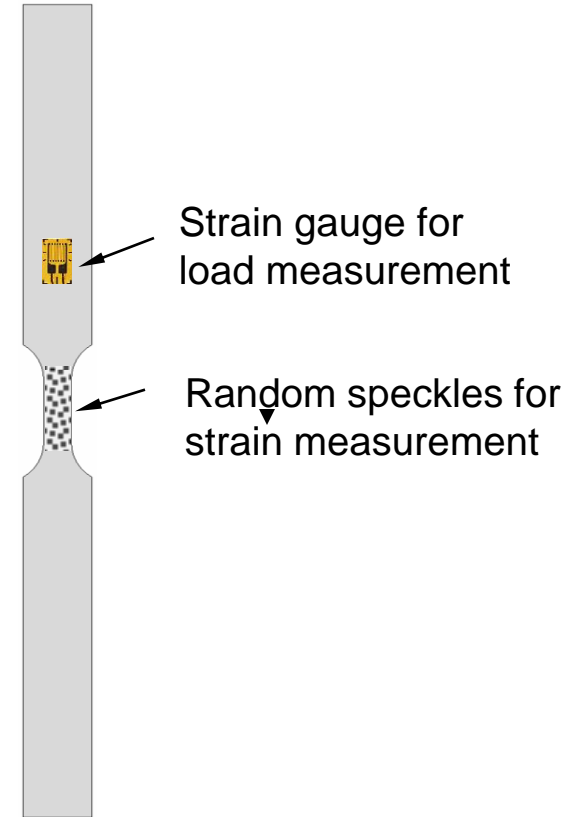
High strain rate test with DIC system



High Strain Rate Test



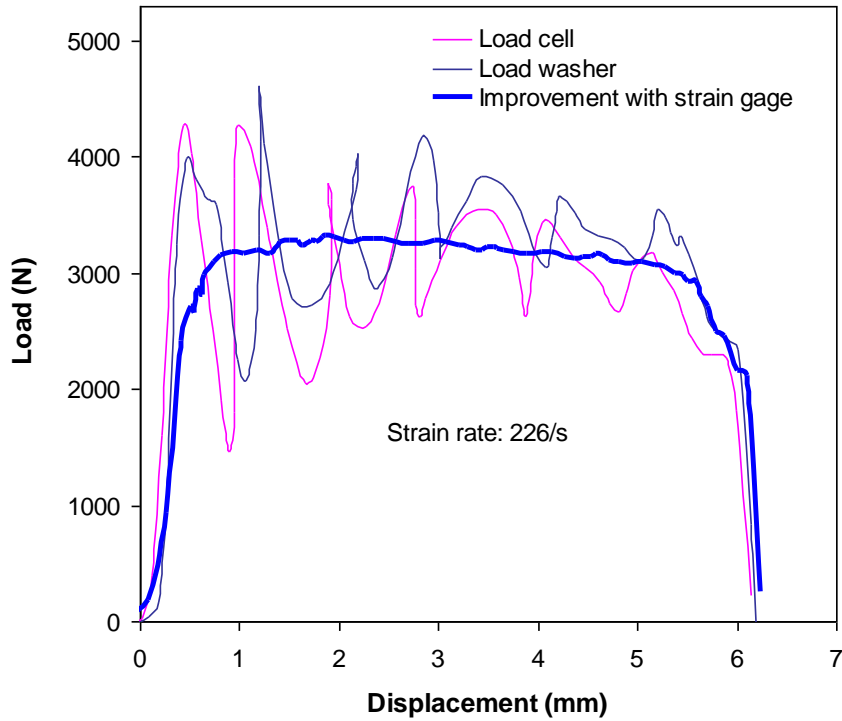
Schematic of testing setup



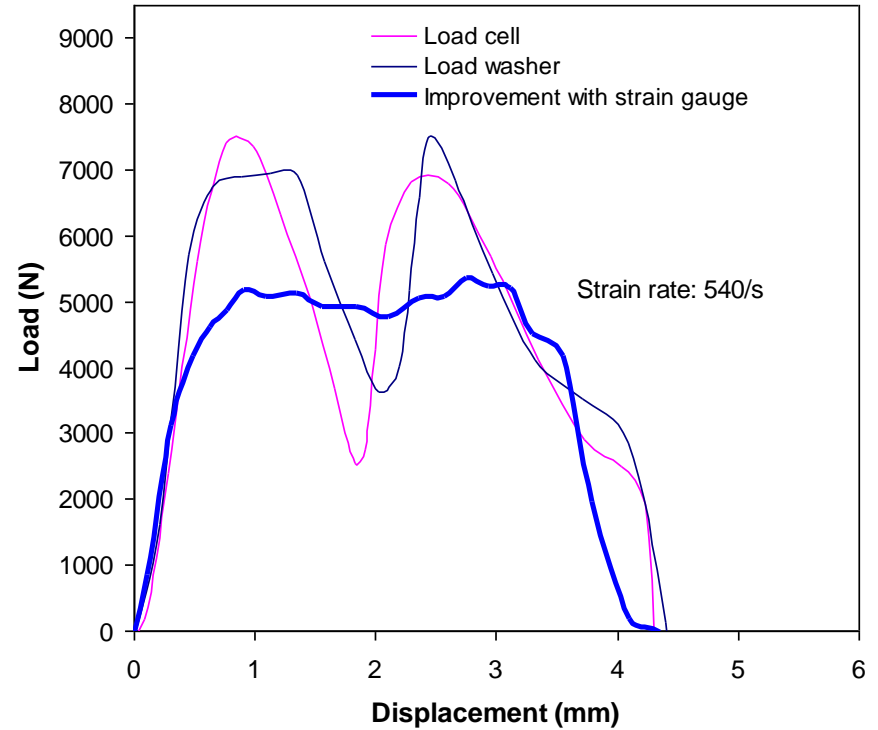
High strain rate specimen



High Strain Rate Test – Load Signal Improvement



Load-displacement curves of DP590 at 220/s



Load-displacement curves of DP780 at 550/s





Materials

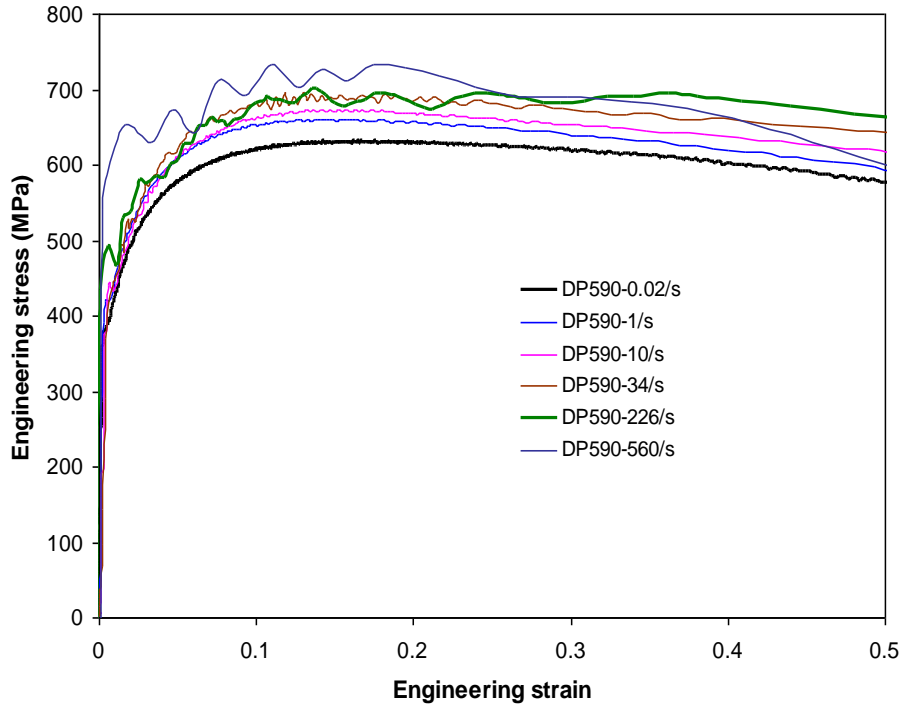
Tensile Properties

| 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 |

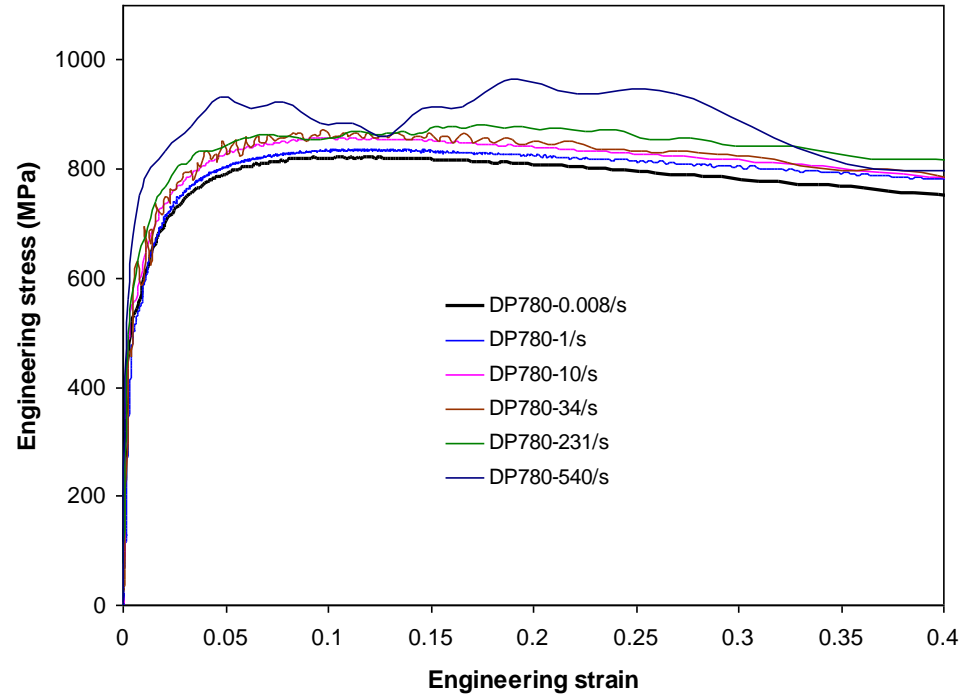




Stress-strain Curves



Engineering stress-strain curves of DP590

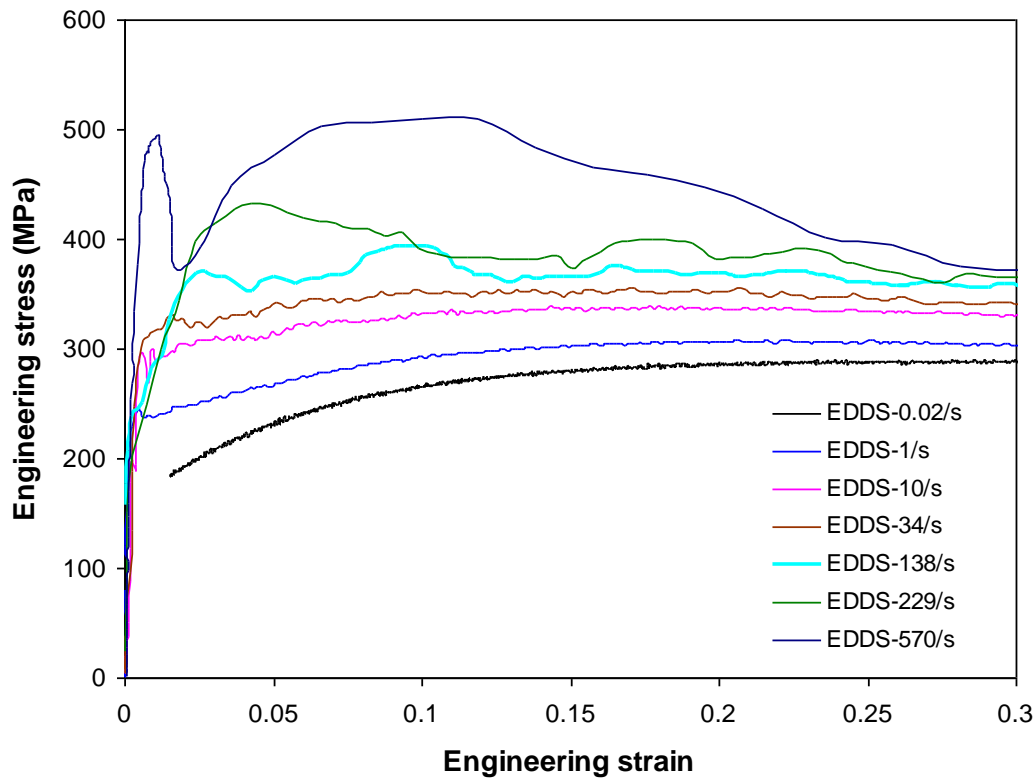


Engineering stress-strain curves of DP780





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

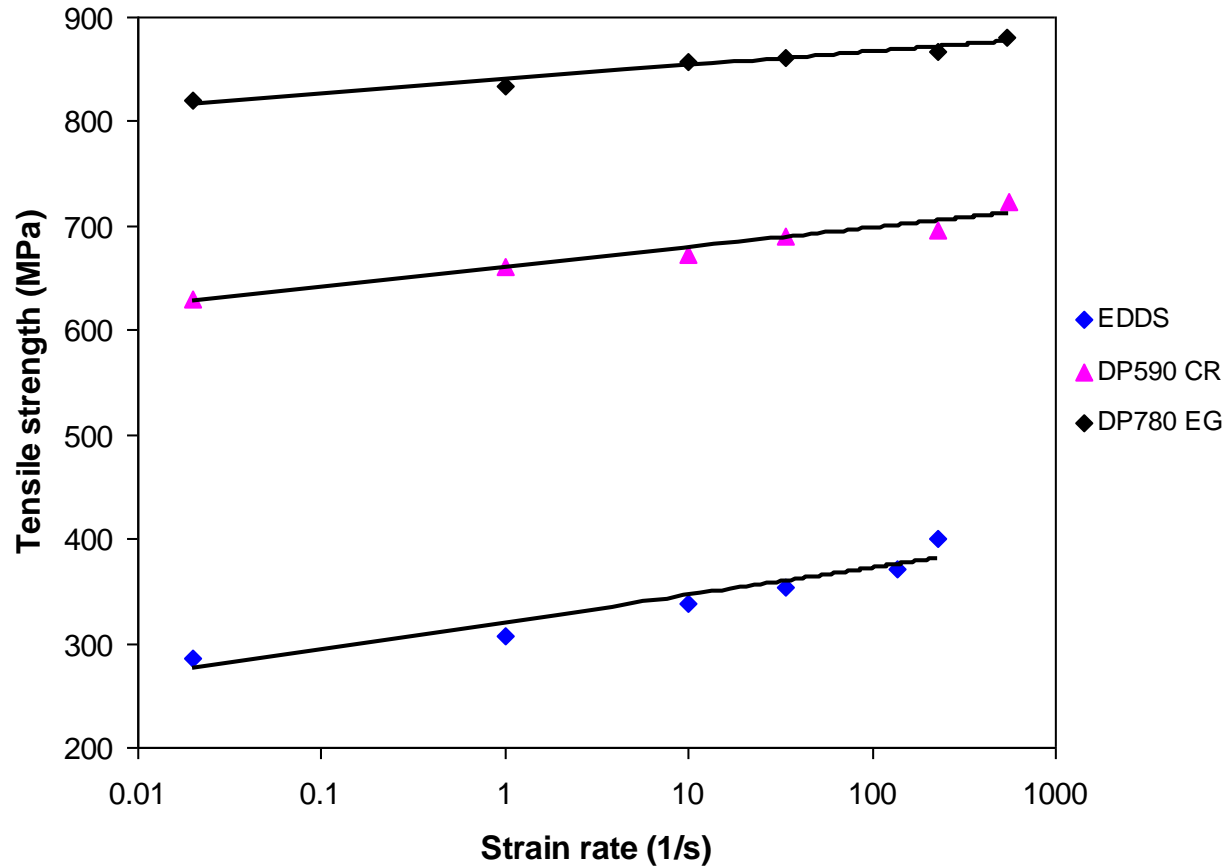
| Tensile properties | 0.02 /s | 1 /s | 10 /s | 34 /s | 226 /s | 560 /s |
|--------------------|---------|-------|-------|-------|--------|--------|
| UTS (MPa) | 630 | 660 | 672 | 690 | 696 | 723 |
| UE | 0.17 | 0.168 | 0.175 | 0.169 | 0.175 | 0.174 |
| TEL (5mm GL) | 0.547 | 0.467 | 0.517 | 0.55 |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



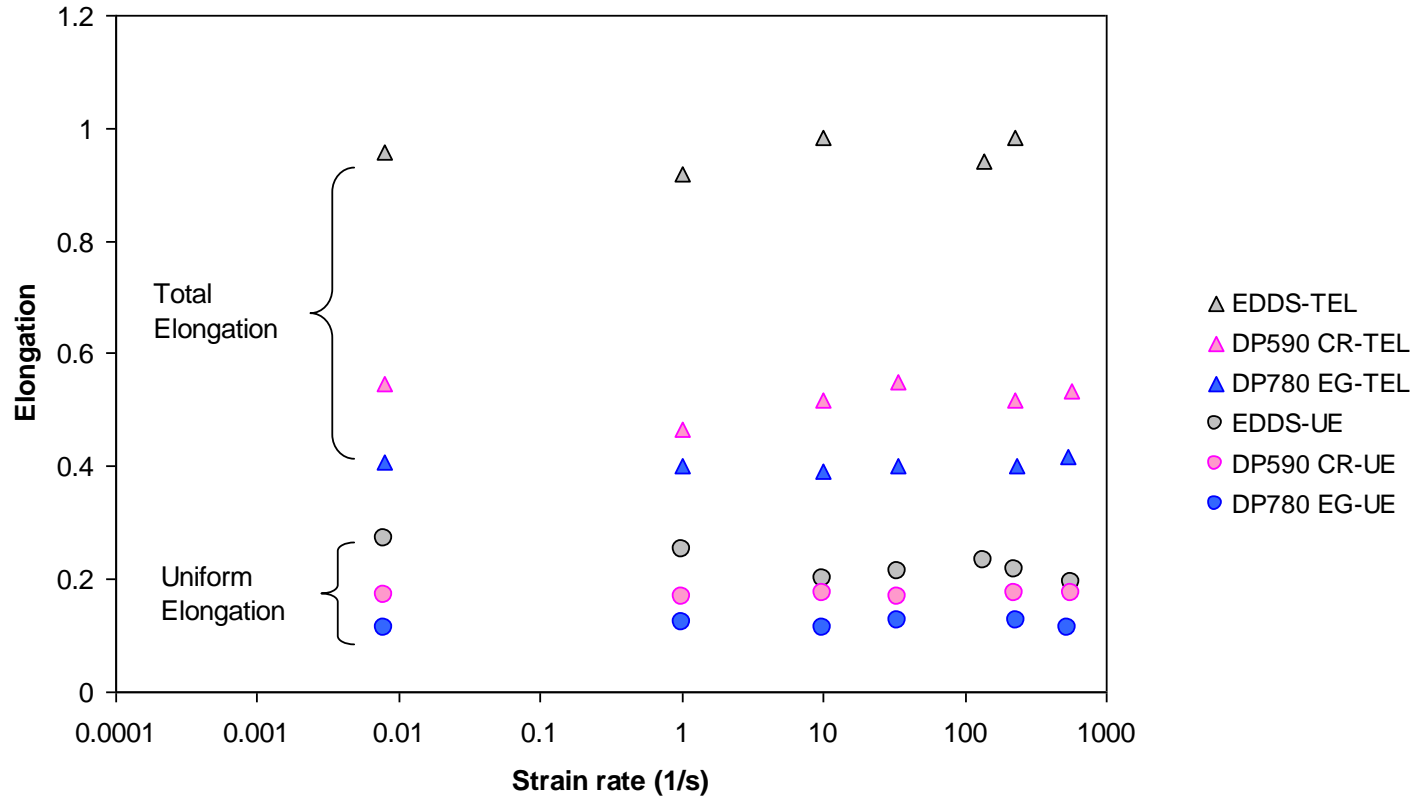
Strain Rate Effect on Tensile Strength



Relation between tensile strength and strain rate



Strain Rate Effect on Elongations



Uniform elongation and total elongation with respect to strain rate

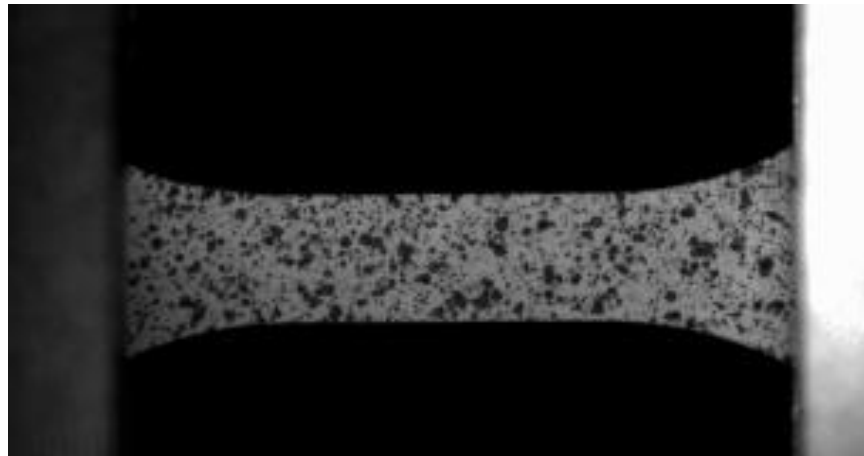


Strain Rate Effect on tensile fracture strain

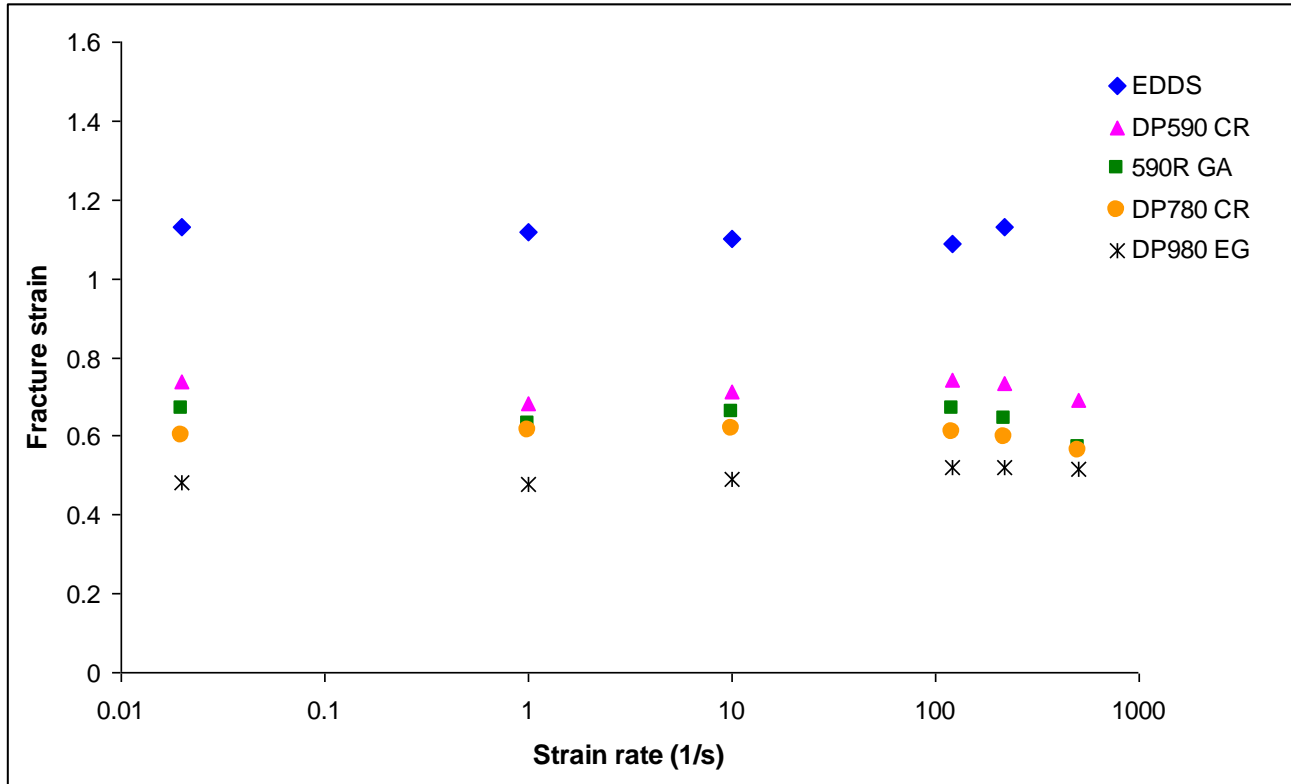
Fracture strain of 5 materials at different strain rates

| 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)

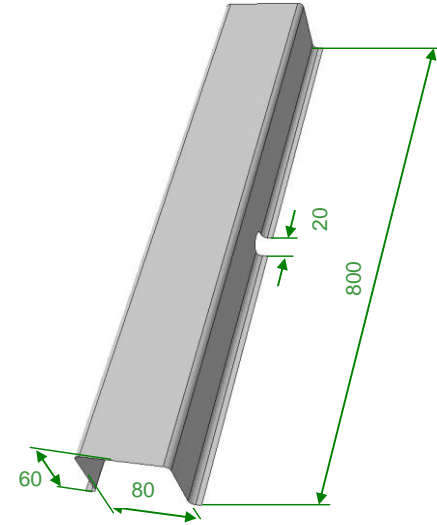
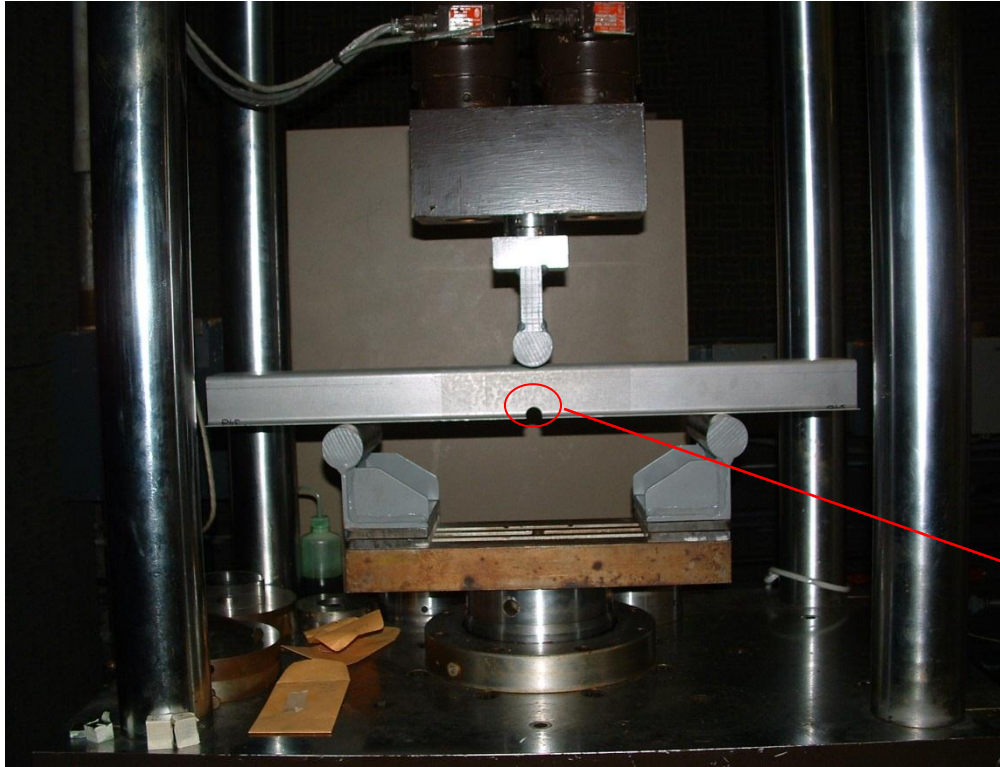


Strain Rate Effect on fracture strain





3-point Bending Beam Tests – Quasi-static



Test setup of quasi-static beam test and specimen





ArcelorMittal

3-point Bending Beam Tests – Dynamic

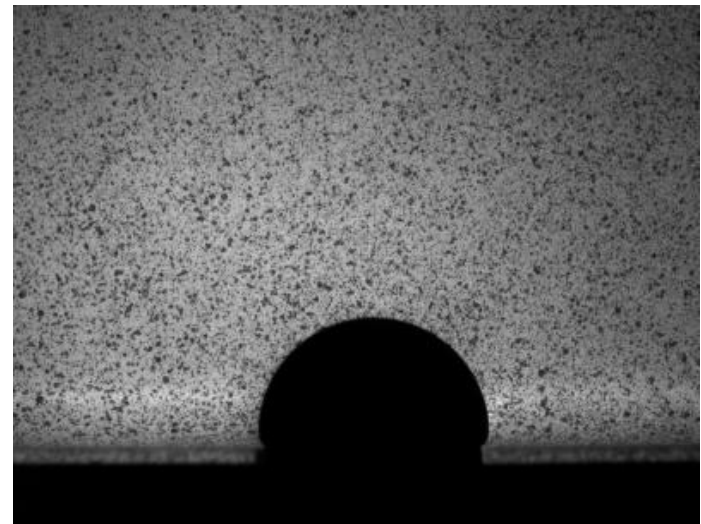




Strain Rate Effect on Edge fracture strain

| 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.

