# Development of a segregation neutralised dual phase steel for improved formability

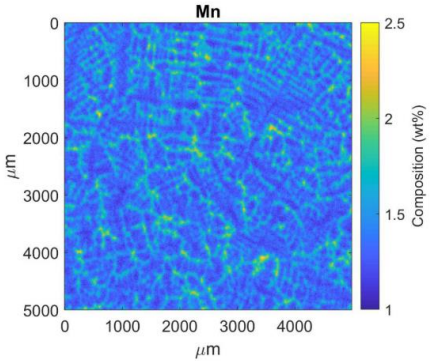
Pedram Dastur, Dr. Carl Slater, Dr. Bharath Bandi and Prof. Claire Davis

# Conventional Dual Phase (DP) steel

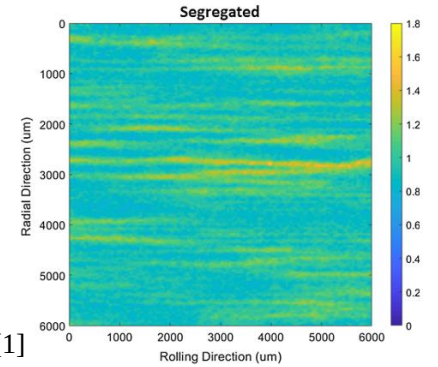
## Typical microstructure

Manganese segregation

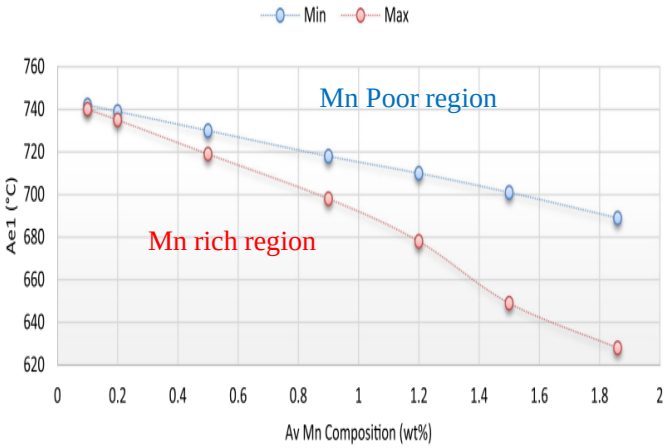
As-cast




Cold rolled




[1]





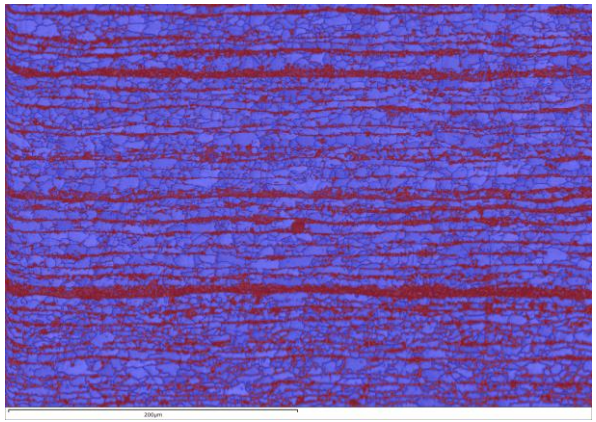
Banded distribution of second phase

[1] C. Slater, A. Mandal, C. Davis, Metall. Mater. Trans. B Process Metall. Mater. Process. Sci. 50 (2019).

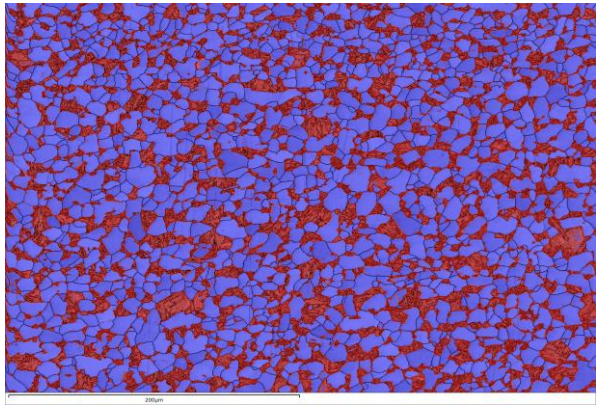
# Changing the morphology of second phase

**What are the benefits?**

Banded



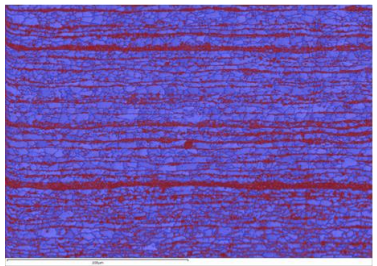
Non-Banded



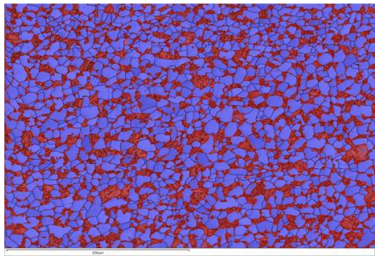
# Changing the morphology of second phase

## What are the benefits?

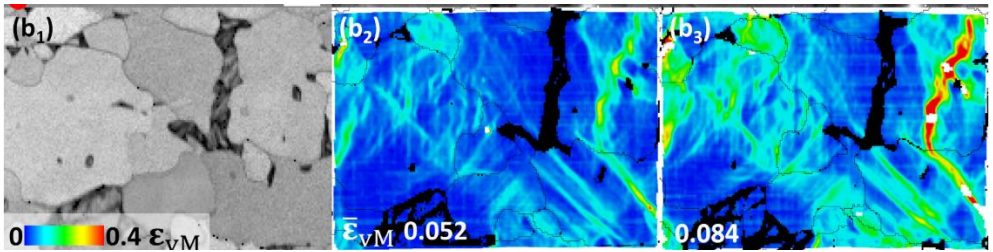
Banded



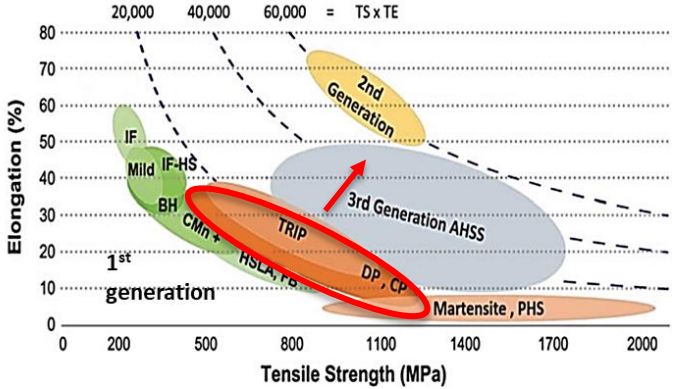
Non-Banded



High localised strain at the vicinity of massive martensite




**Global formability**




Improved global formability is expected

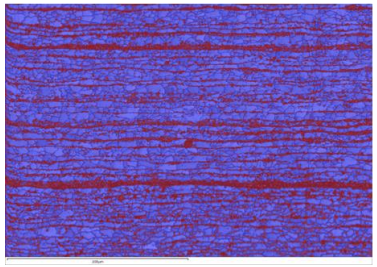
C.C. Tasan, J.P.M. Hoefnagels, M. Diehl, D. Yan, F. Roters, D. Raabe, Int. J. Plast. 63 (2014) 198–210.

# Changing the morphology of second phase

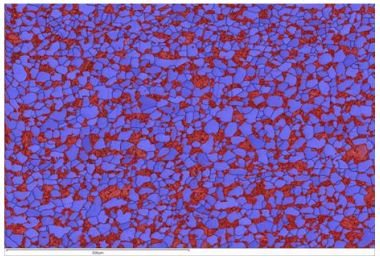
**What are the benefits?**

**Local formability**

Banded



Non-Banded



Autobody components with complex shapes

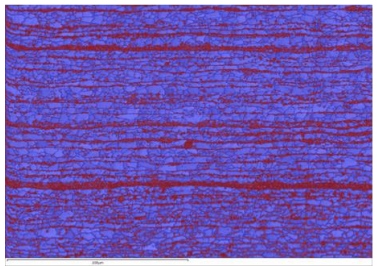


S. Keeler, M. Kimchi, P.J. Mooney, WorldAutoSteel (2017) 314.

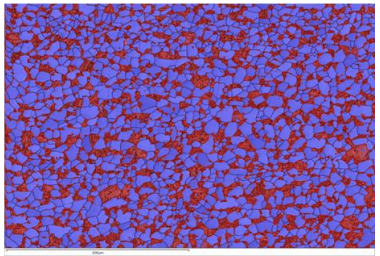
# Changing the morphology of second phase

**What are the benefits?**

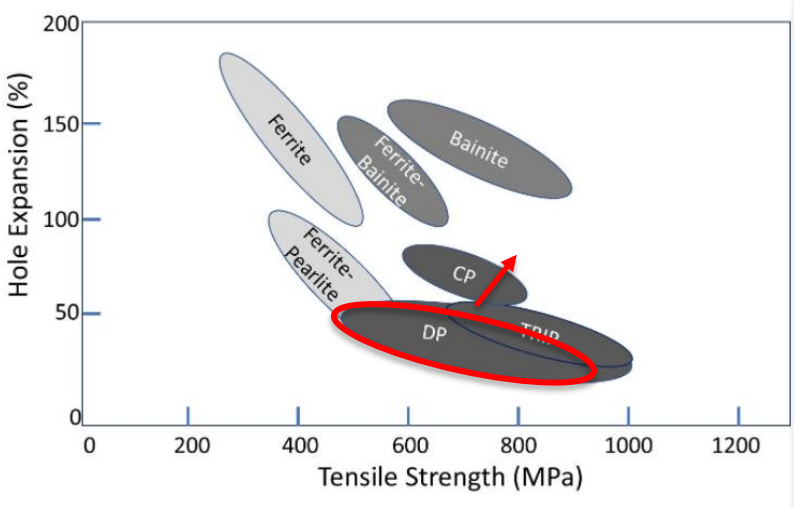
Banded



Non-Banded



**Local formability**




Improved local formability is expected



S. Keeler, M. Kimchi, P.J. Mooney, WorldAutoSteel (2017) 314.

# Segregation neutralised (SN) DP steel

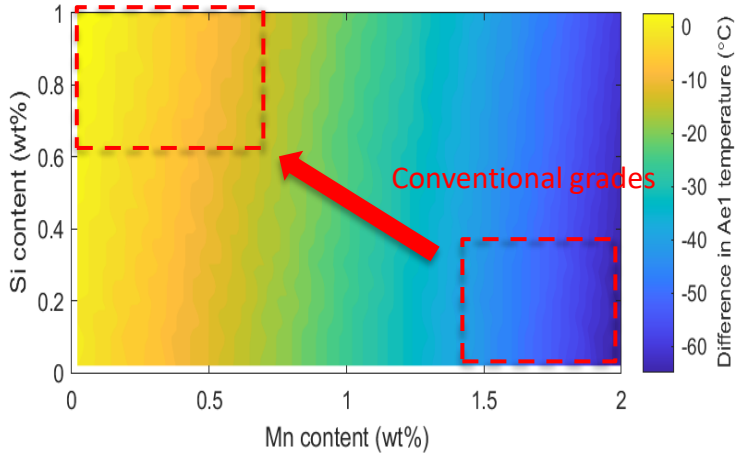
Neutralising the effect of Mn segregation on second phase distribution

Idea

Changing morphology of second phase

Solution

Redesigning the chemical composition of DP steel




| Benchmark DP steel | | | | | |
|---|---|---|---|---|---|
| **Fe** | **C** | **Mn** | **Cr** | **Si** | **Nb** |
| Bal. | 0.13 | 1.86 | 0.55 | 0.25 | 0.03 |

| SN-DP-initial composition | | | | | |
|---|---|---|---|---|---|
| **Fe** | **C** | **Mn** | **Cr** | **Si** | **Nb** |
| Bal. | 0.13 | 0.25 | 0.55 | 0.75 | 0.03 |

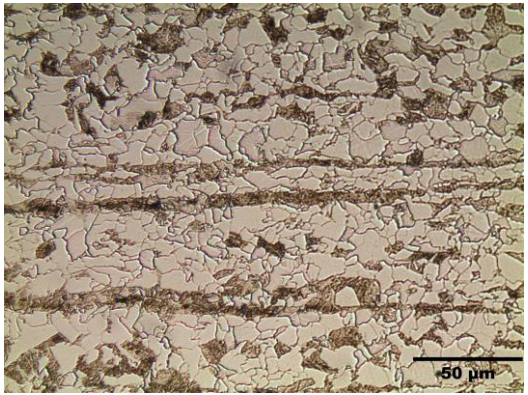


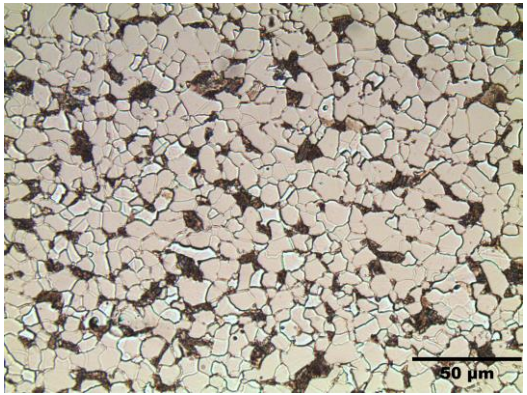
C. Slater, B. Bandi, P. Dastur, C. Davis, Metall. Mater. Trans. A Phys. Metall. Mater. Sci. 53 (2022) 2286–2299.

# Hot rolled microstructure

Benchmark-DP

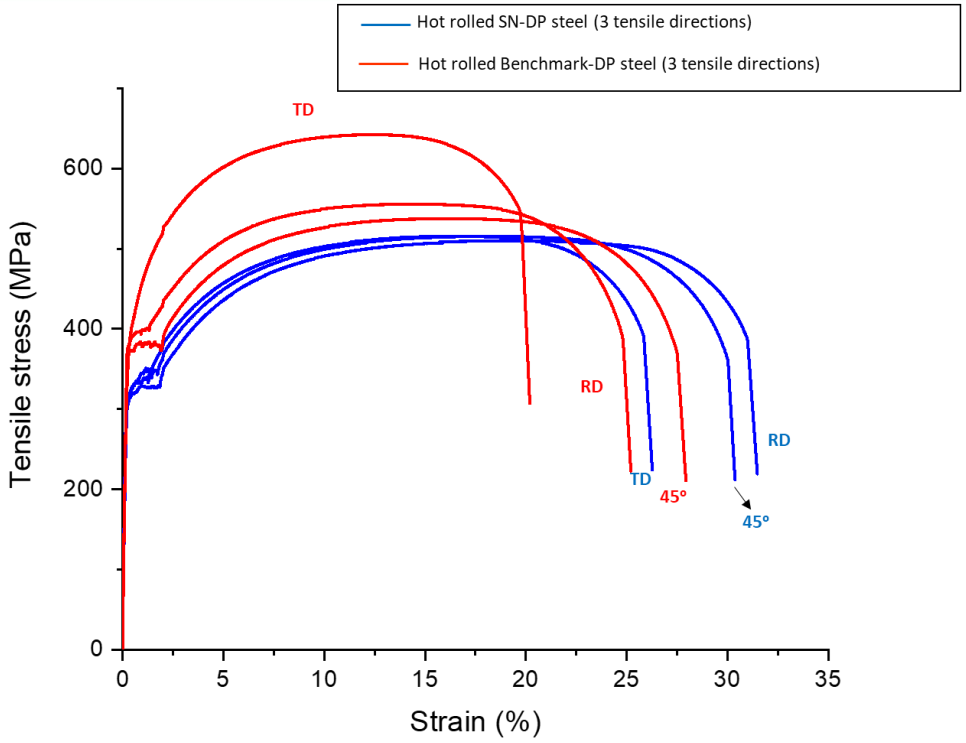
SN-DP




C. Slater, B. Bandi, P. Dastur, C. Davis, Metall. Mater. Trans. A Phys. Metall. Mater. Sci. 53 (2022) 2286–2299.

# Global formability (hot rolled)

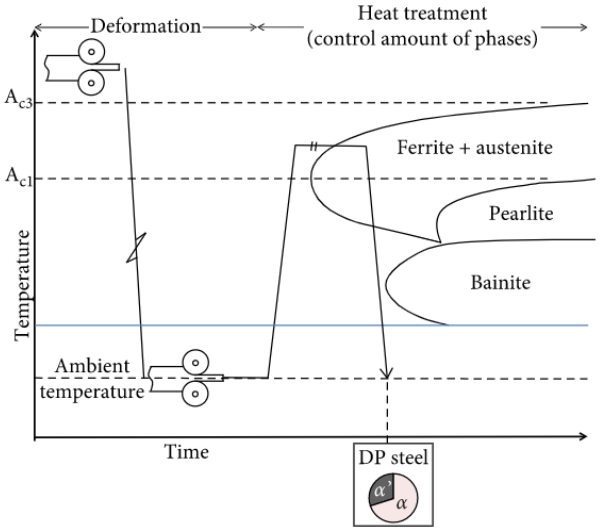



| UTS (MPa) | RD | TD | 45° |
|---|---|---|---|
| Benchmark-DP | 550 | 645 | 535 |
| SN-DP | 505 | 515 | 515 |

- Lower tensile anisotropy in SN-DP
- Higher elongation in SN-DP
- Lower strength in SN-DP

(might be due to a larger grain size)

# Processing of DP steel

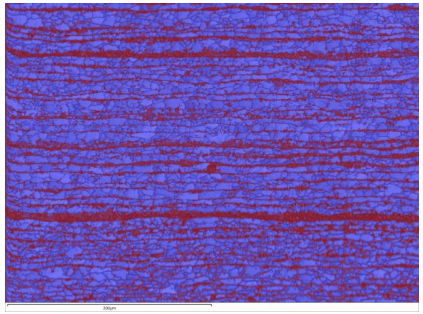


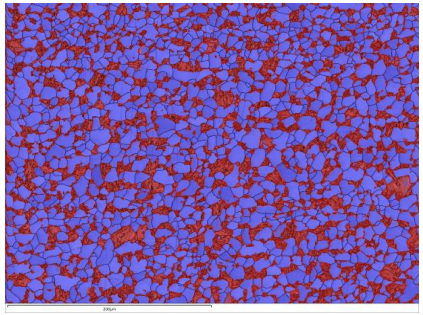

Conventional processing route

Benchmark-DP

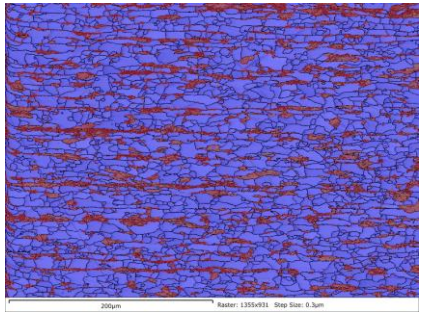
SN-DP

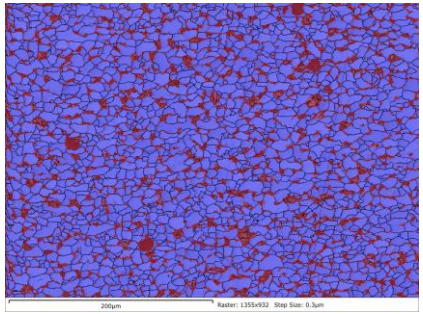
$V_m$ ~ 35-40%





$V_m$ ~ 25%

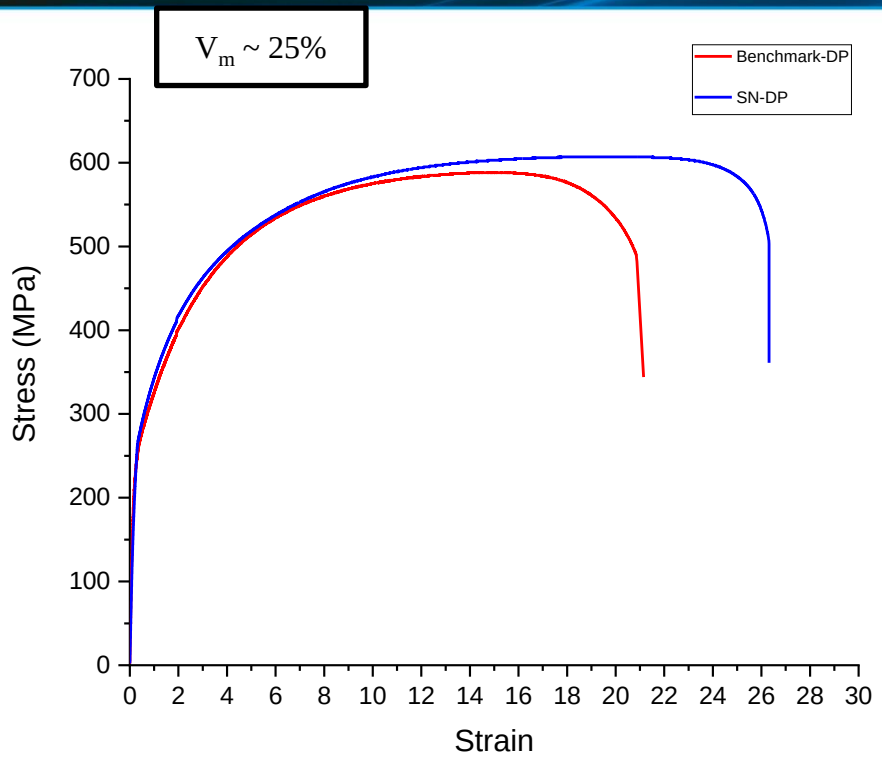






L. Van Long, D. Van Hien, N.T. Thanh, N.C. Tho, V.T. Do, Adv. Mater. Sci. Eng., (2020).

# Global formability (After annealing)




- Higher elongation in SN-DP

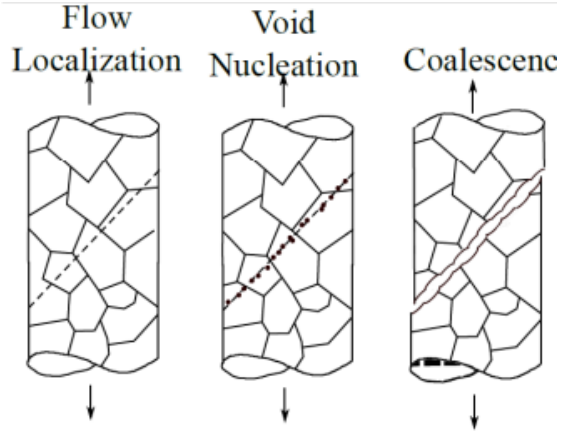
| | UTS (MPa) | Uniform elongation (%) | Total elongation (%) |
|---|---|---|---|
| Benchmark-DP | 592 | 15 | 21 |
| SN-DP | 605 | 20 | 26 |

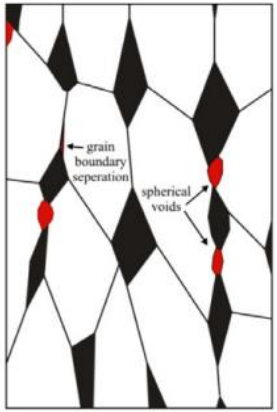
# Local formability study

Local formability

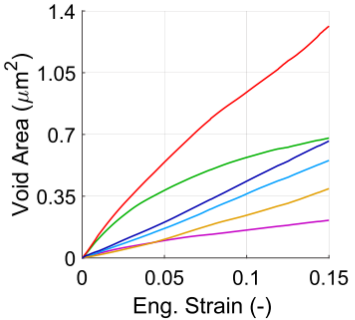
DP steel

Martensite morphology

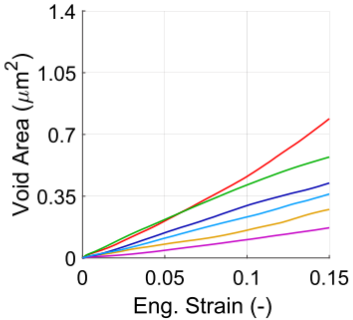



Banded morphology




Random morphology




Void coalescence in shear bands

High void formation rate

Higher local formability in random morphology

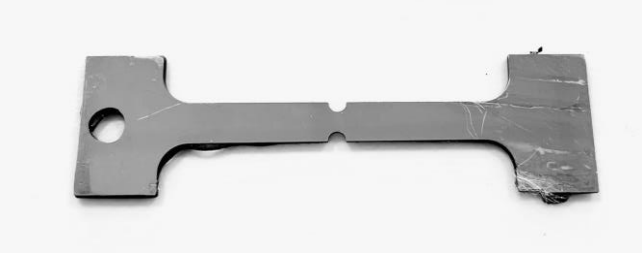
E.E. Aşik, E.S. Perdahcioğlu, T. van den Boogaard, Materials (Basel). 13 (2020).

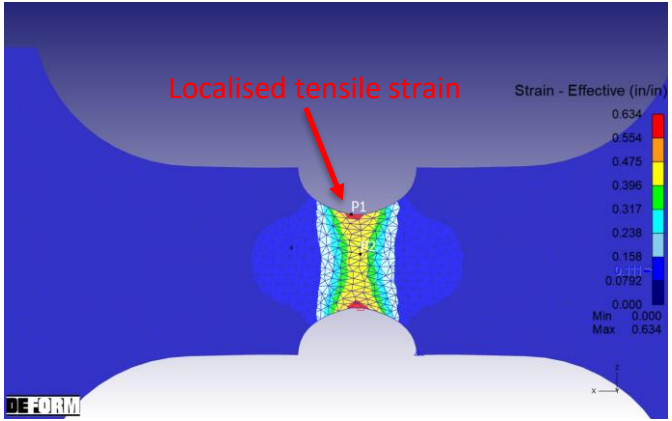
J. Kadkhodapour, A. Butz, S. Ziaei Rad, Acta Mater. 59 (2011) 2575–2588.

# Local formability study

**Methodology**

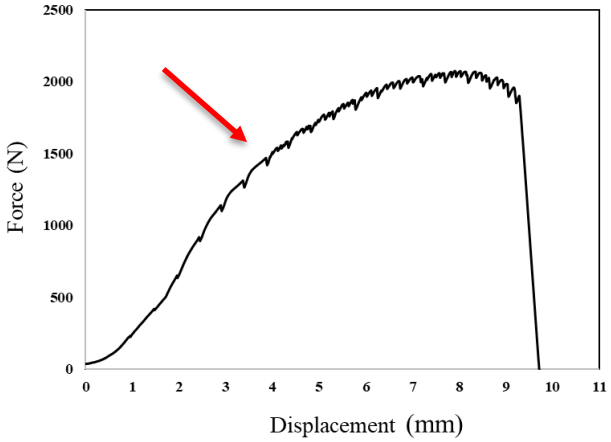
In-situ notched tensile test in SEM

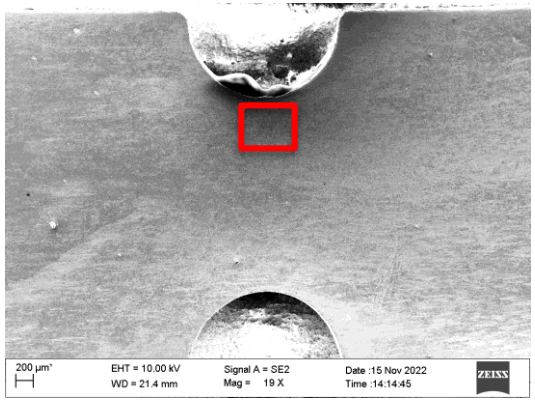


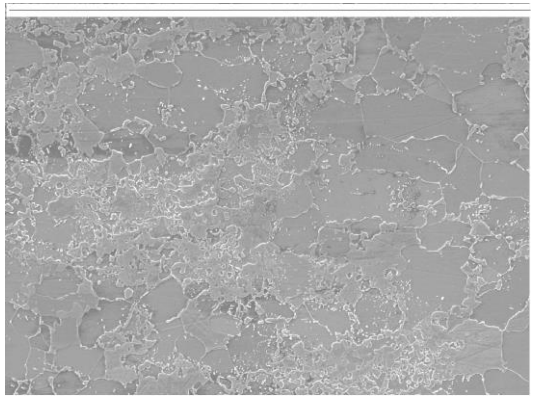



Localised tensile stress at the Edge (similar to hole-expansion test)

# Local formability study



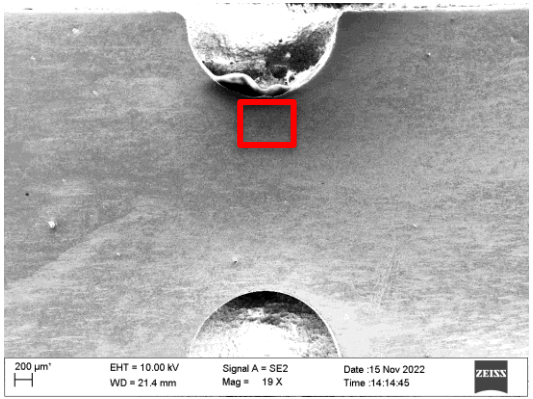



**12 µm**

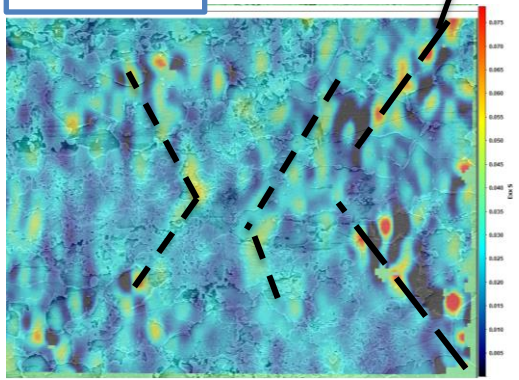
# Local formability study

DIC analysis

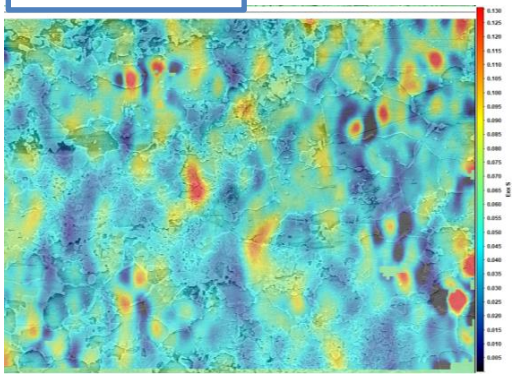



**Shear bands**

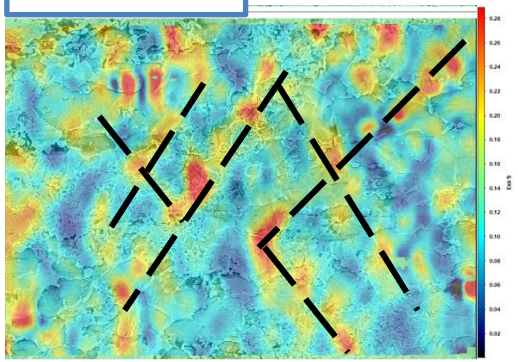
δ = 0.3 mm



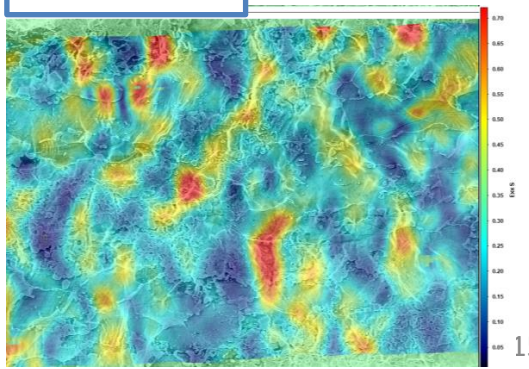
δ = 0.55 mm



δ = 0.75 mm



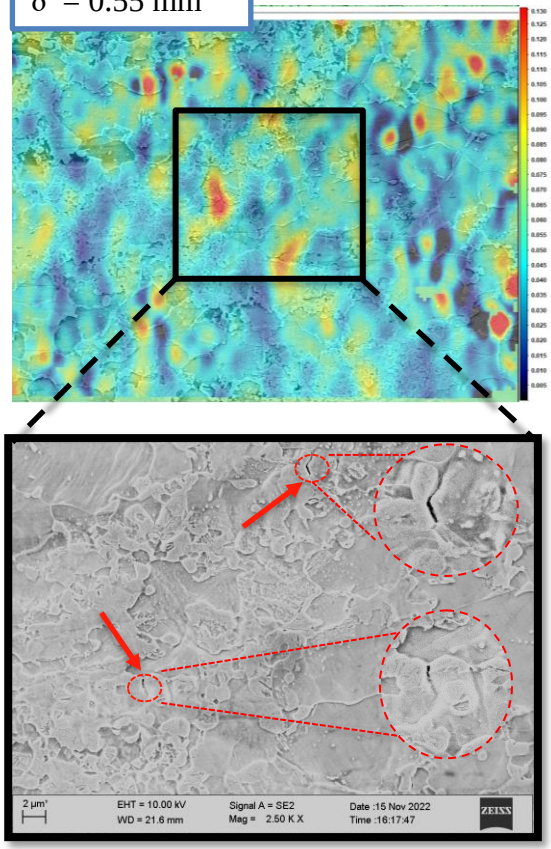
δ = 0.94 mm



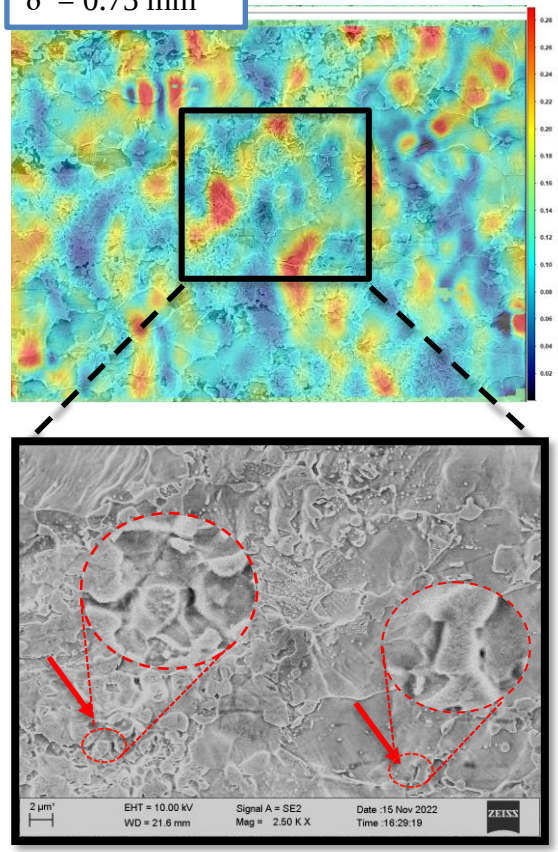
# Local formability study

Void nucleation analysis

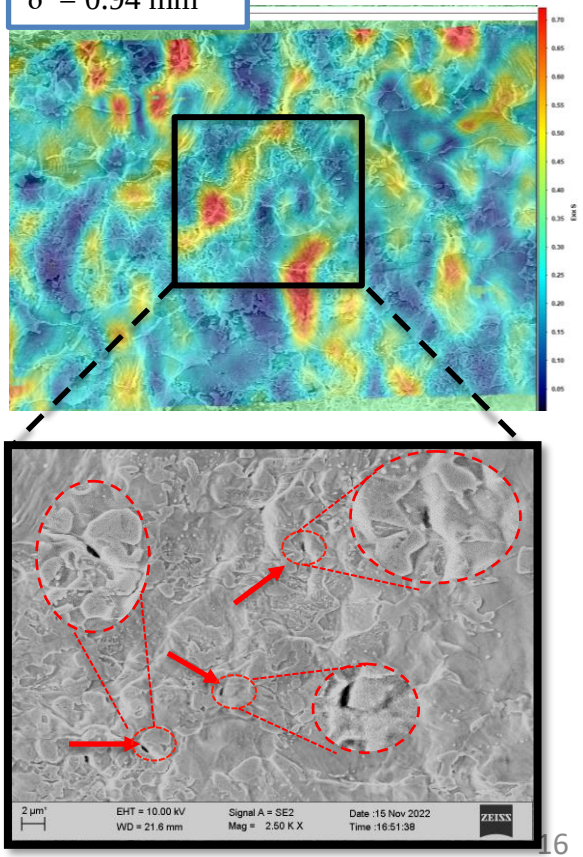
δ = 0.55 mm




δ = 0.75 mm



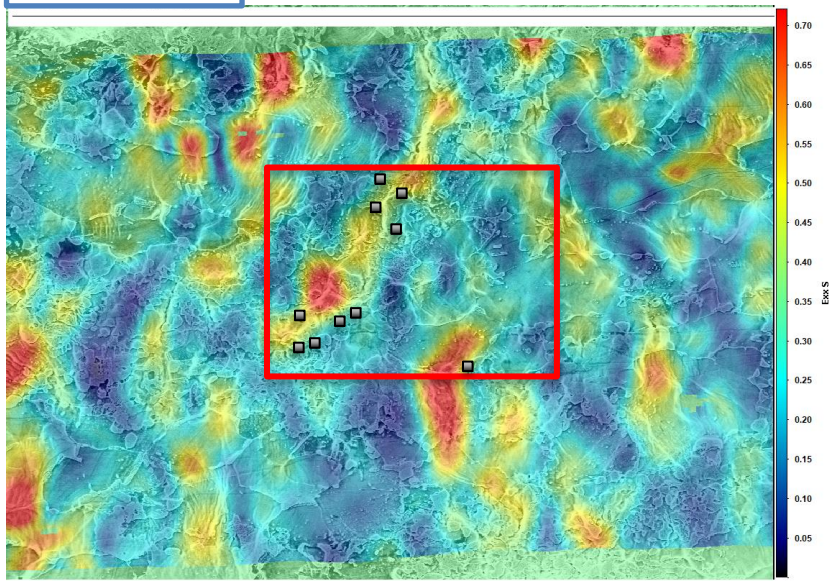

δ = 0.94 mm



# Local formability study

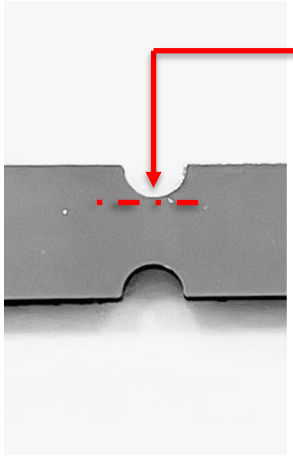
Void nucleation analysis

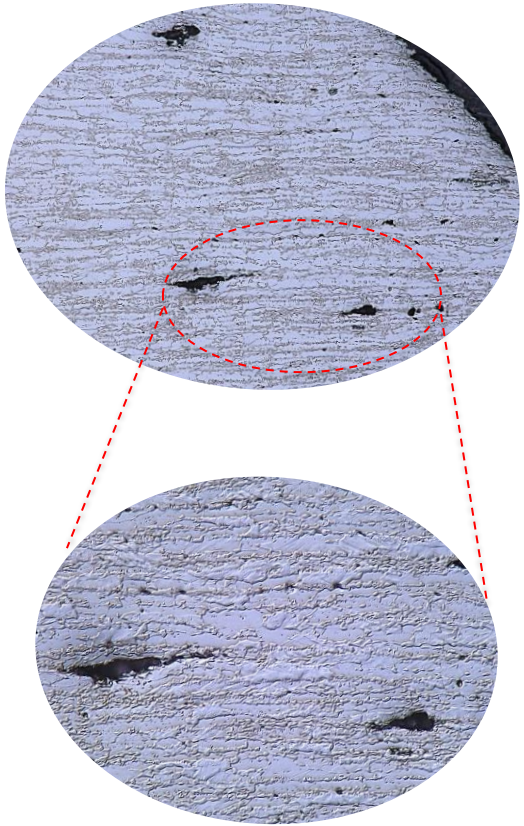
δ = 0.94 mm



# Local formability study

Effect of martensite morphology on void orientation





Formation of voids along martensite bands

# Summary

- The concept of changing the morphology of second phase has been used to improve the formability of DP steels.
- To change the morphology of second phase, chemical composition of conventional DP steel has been redesigned to neutralise the effect of Mn segregation on second phase distribution.
- Hot rolled SN-DP showed lower tensile anisotropy compared to Benchmark-DP.
- The higher combination of strength and elongation observed in the processed SN-DP compared to Benchmark-DP with similar grain size.
- Local formability study is carried out by using in-situ tensile test within SEM chamber. It shows the rate of void nucleation in shear bands and also the orientation of voids compared to martensite islands.

**In progress**

- Comparing the void nucleation rate between SN-DP and Benchmark-DP

**Thank you for your attention**