EFFECT OF HETEROGENEOUS MICROSTRUCTURE ON GLOBAL MECHANICAL PROPERTIES OF WELDED JOINT

Nenad Gubeljak[1], Stijn Hertelé [2], Primož Štefane[1], Jožef Predan[1], Wim De Waele[2]

1)University of Maribor, Faculty of Mechanical Engineering, Smetanova 17, 2000 Maribor, Slovenia
2) Ghent University, Soete Laboratory, Technologiepark Zwijnaarde 903, 9052 Zwijnaarde, Belgium12

nenad.gubeljak@um.si

Standard BS 7448: Part 2: 1997:
“The tensile properties of the region in which the crack tip lies are required, at the fracture toughness test temperature for calculation of fracture toughness and qualification assessment!”

Questions:

⇒ How to determine real tensile properties?

⇒ What can be expected difference of results obtained by different tensile tests?

⇒ How two or more microstructures interacted to tensile properties?

2

Experimental investigation:

Mechanical properties of parent metal, overmatched and undermatched consumable (by producer specification):

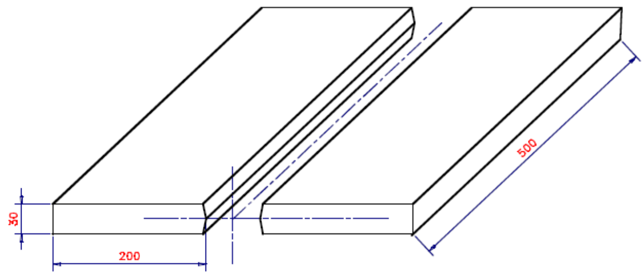
Material	Lebel	$R_{p0.2}$ MPa	R_m MPa	M $R_{p0.2WM}/R_{p0.2BM}$	Charpy Kv J/80mm^2
Overmatch	FILTUB 75	700	780	1.37	>40 J at -60°C
Base metal	NIOMOL 490	510	650	-	>60 J at -60°C
Undermatch	VAC 60	437	556	0.86	>80 J at -50°

Actual chemical composition (in weight %):

Material	C	Si	Mn	P	S	Cr	Mo	Ni
Overmatch	0.040	0.16	0.95	0.011	0.021	0.49	0.42	2.06
Base metal	0.123	0.33	0.56	0.003	0.002	0.57	0.34	0.13
Undermatch	0.096	0.58	1.24	0.013	0.16	0.07	0.02	0.03

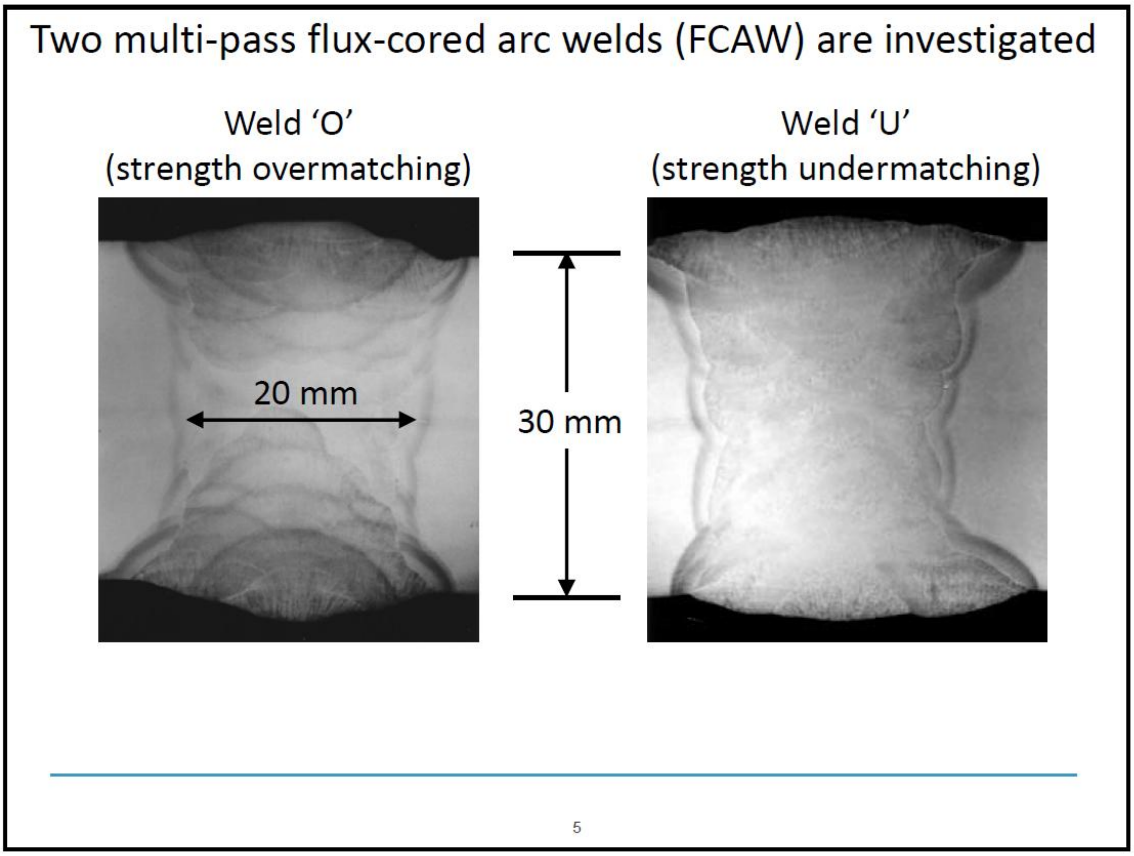
3

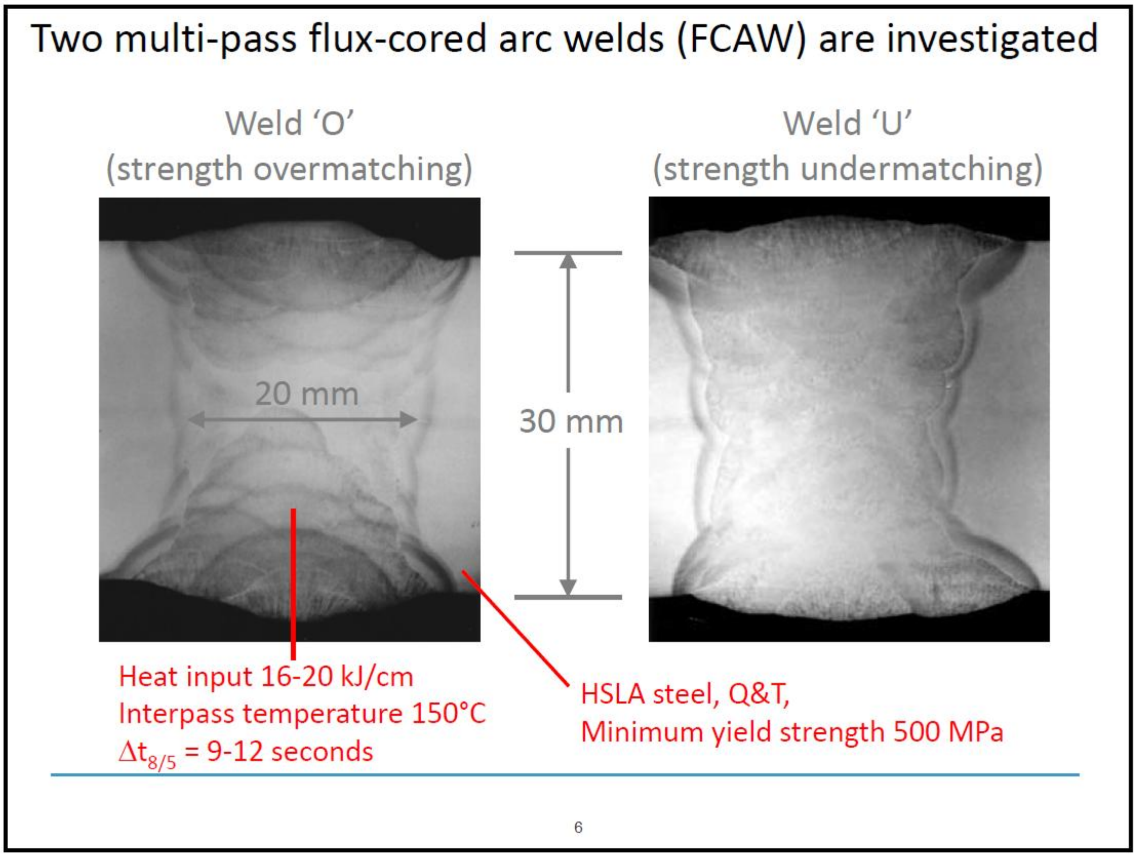
Welding procedure:



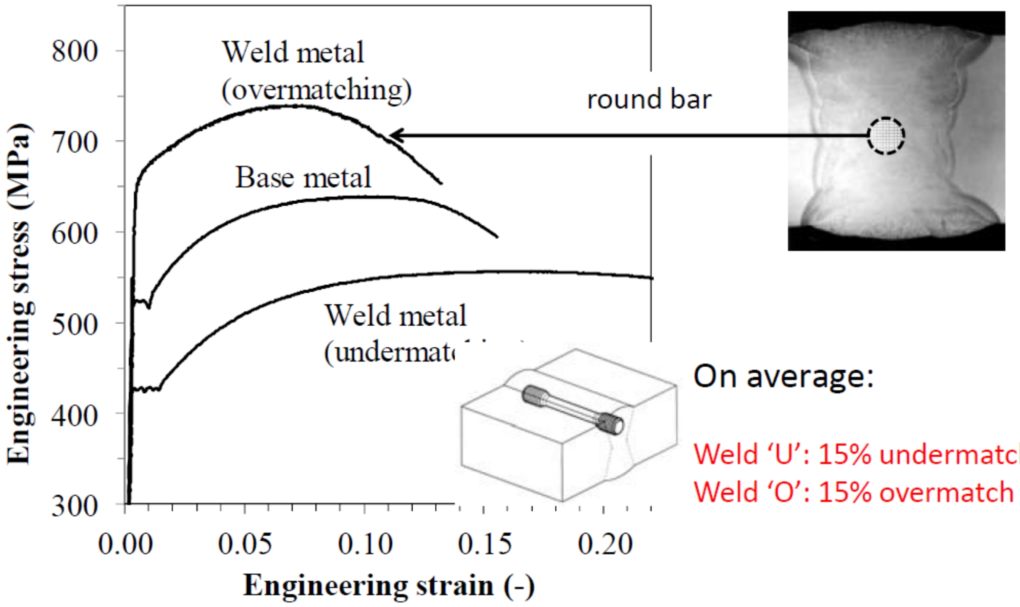
Heat input: Q=16-20kJ/cm; $\Delta t_{8/5}$=9-12s;
Interpass temp: 150°

4


Two multi-pass flux-cored arc welds (FCAW) are investigated
Weld 'O'
(strength overmatching)
Weld 'U'
(strength undermatching)
20 mm
30 mm
5


Two multi-pass flux-cored arc welds (FCAW) are investigated
Weld 'O'
(strength overmatching)
Weld 'U'
(strength undermatching)
20 mm
30 mm
Heat input 16-20 kJ/cm
Interpass temperature 150°C
$\Delta t_{8/5}$ = 9-12 seconds
HSLA steel, Q&T,
Minimum yield strength 500 MPa
6

A wide range of weld strength mismatch levels is covered

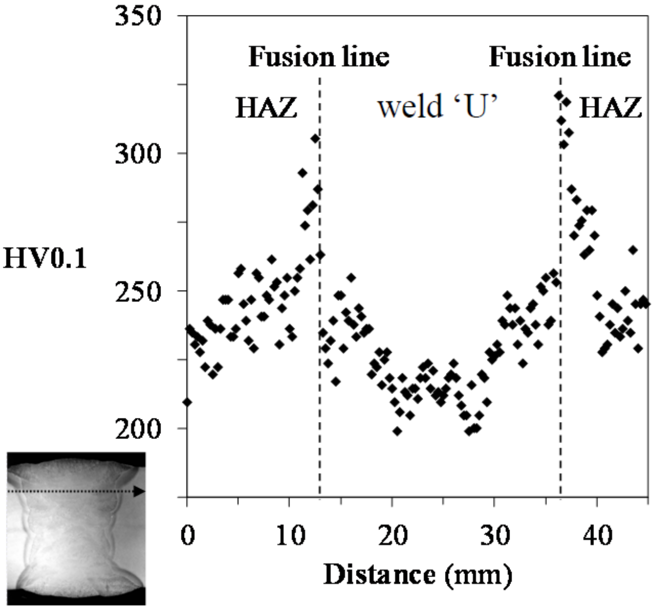


On average:

Weld 'U': 15% undermatch
Weld 'O': 15% overmatch

7

Micro Vickers hardness testing indicates a strong degree of weld heterogeneity



Hardness is related to (ultimate tensile) strength

Good qualitative view on heterogeneity

Highly sensitive to strong strength gradients (e.g. fusion line / coarse grained HAZ)

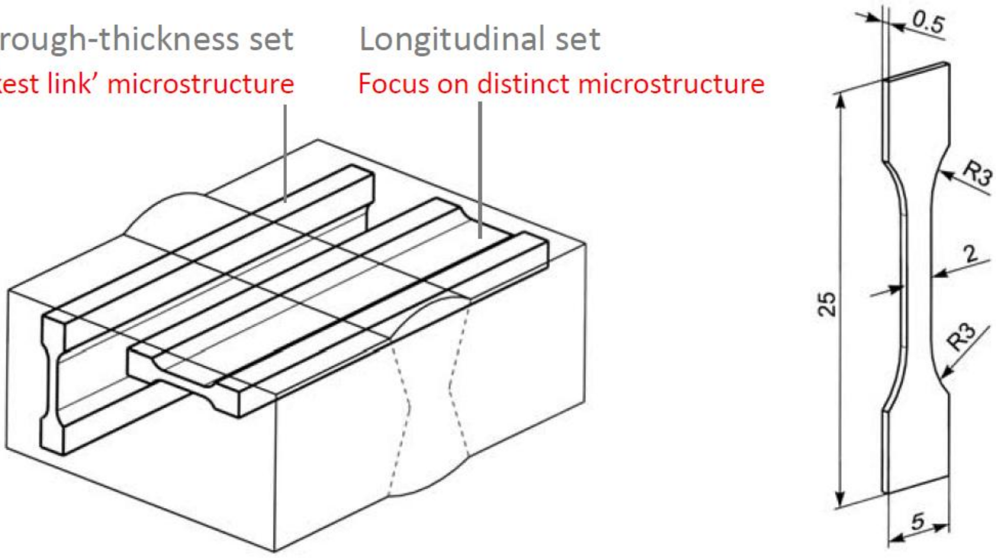
No information about strain hardening

8

Micro tensile testing in two orientations

Through-thickness set
'Weakest link' microstructure

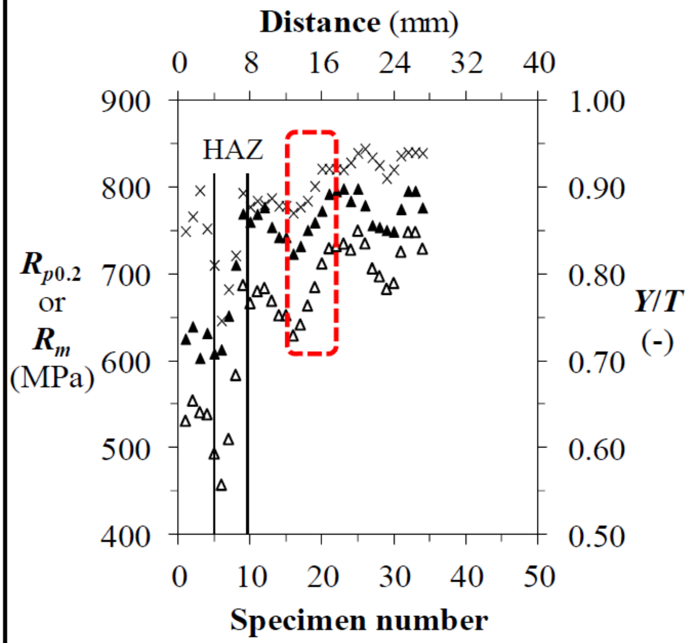
Longitudinal set
Focus on distinct microstructure



Tests performed at Helmholtz-Zentrum Geesthacht, Germany (formerly GKSS)

9

Weld heterogeneity is pronounced

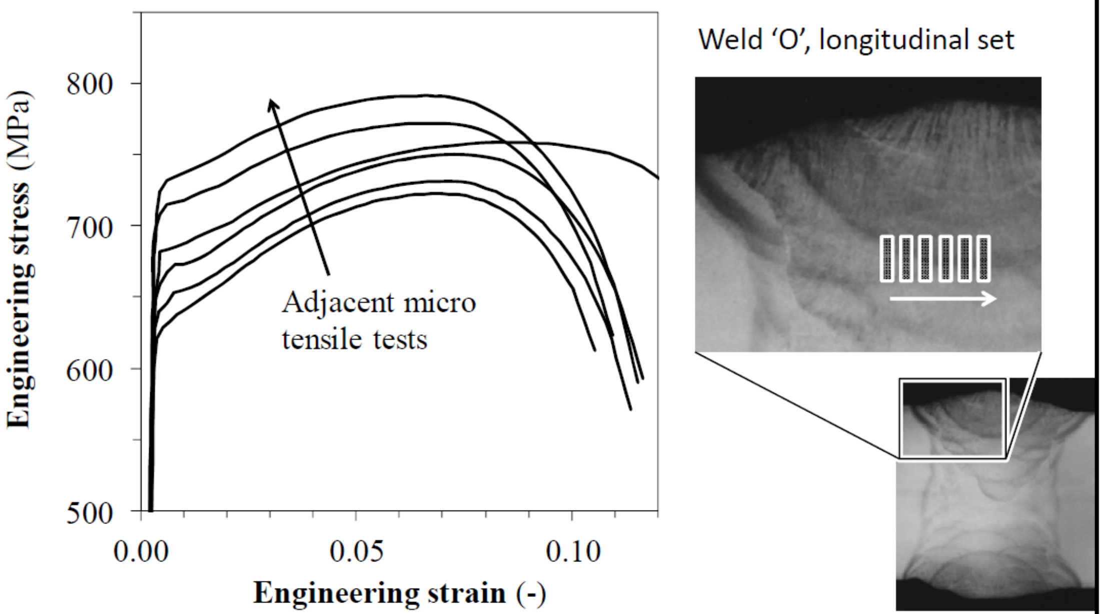


Weld 'O', longitudinal set
(one HAZ sampled only)

Strong strength gradients

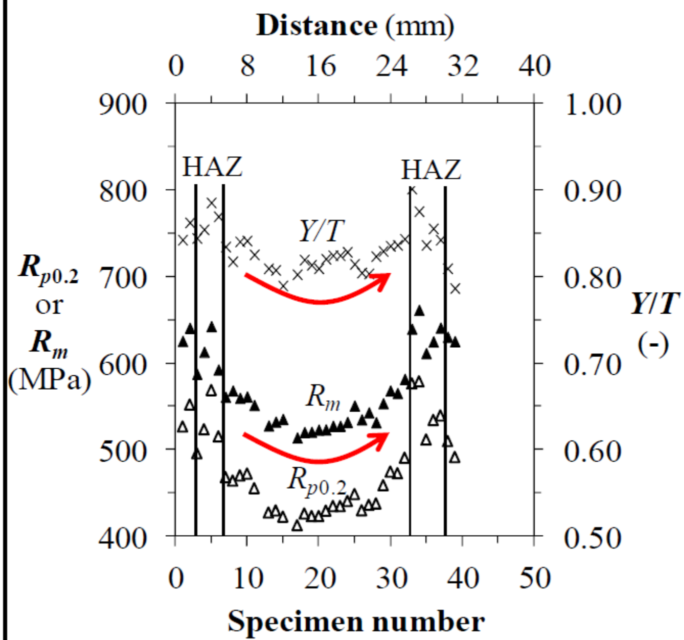
10

Yield and ultimate tensile strength varies up to 100 MPa over a distance of 5 mm (all weld metal)



11

Y/T and strength level are related

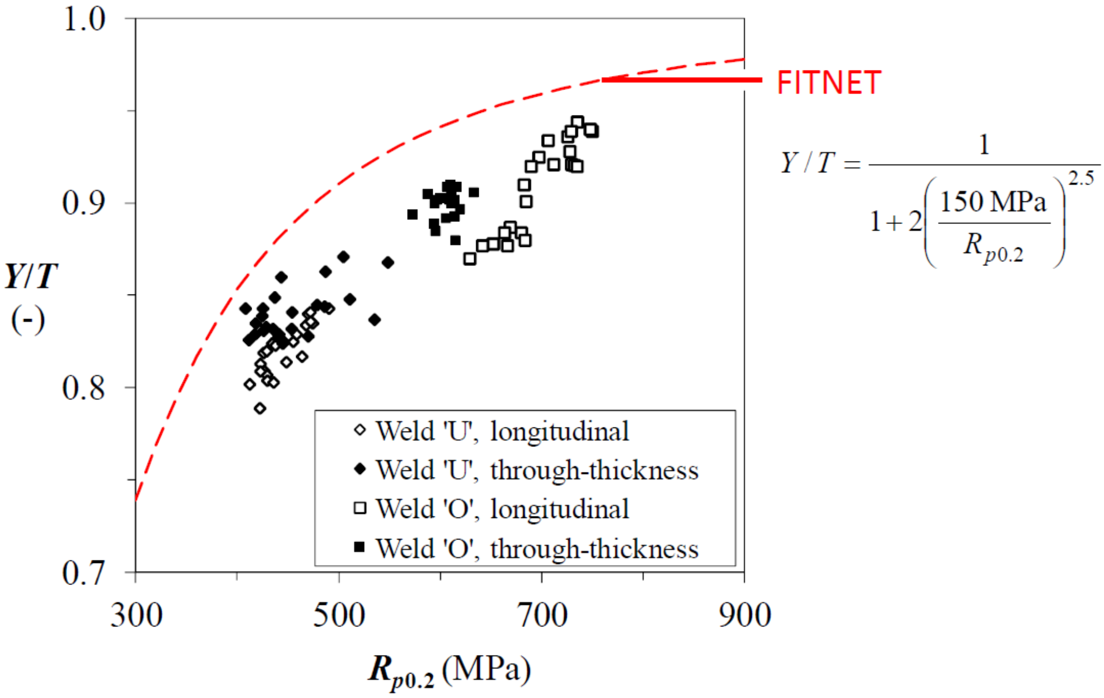


Weld 'U', longitudinal set

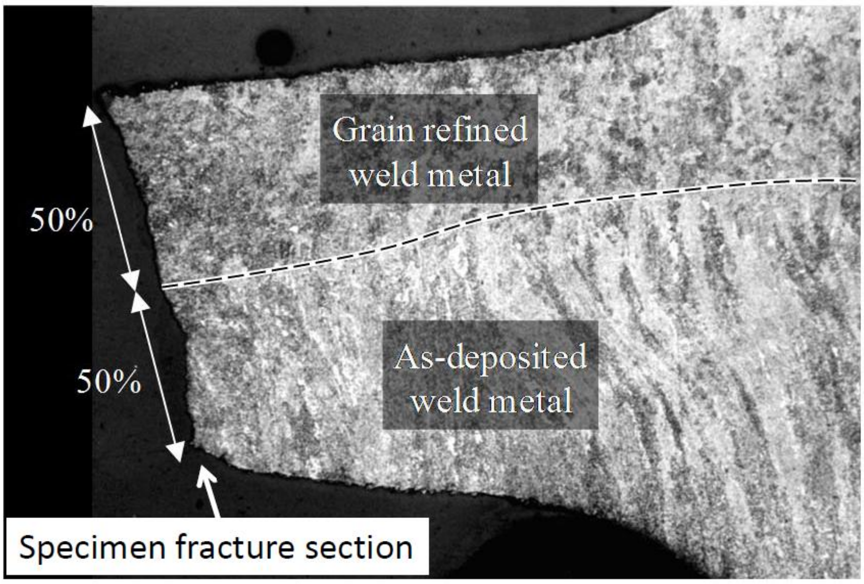
Y/T increases as $R_{p0.2}$ (or R_m) increases and vice versa

12

FITNET upper bound for Y/T is respected
by weld metal specimens

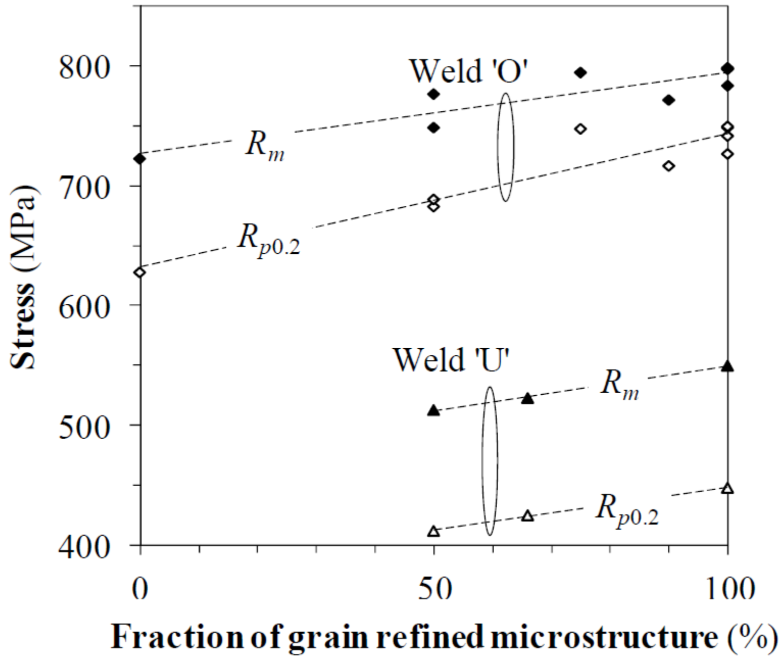


Microstructure has been characterized
at the fracture sections of the tensile test specimens

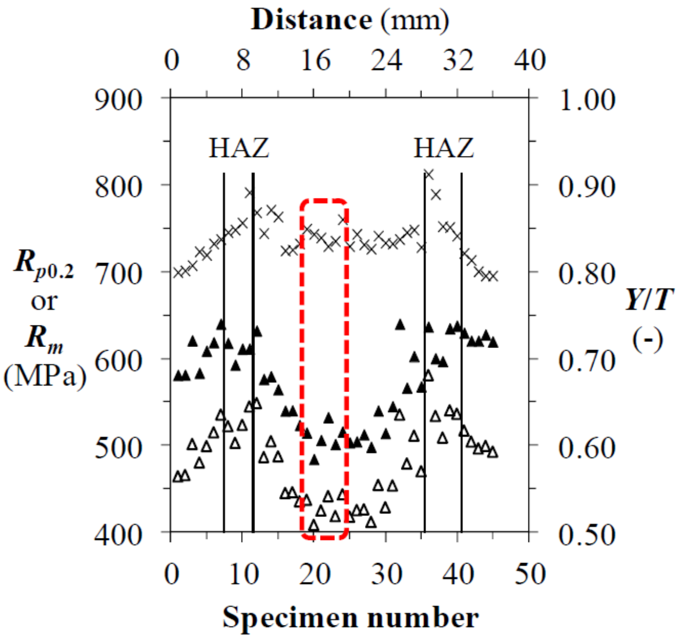


14

Grain refined weld metal tends to be stronger than as-deposited weld metal



At first sight, these tests seem fairly similar



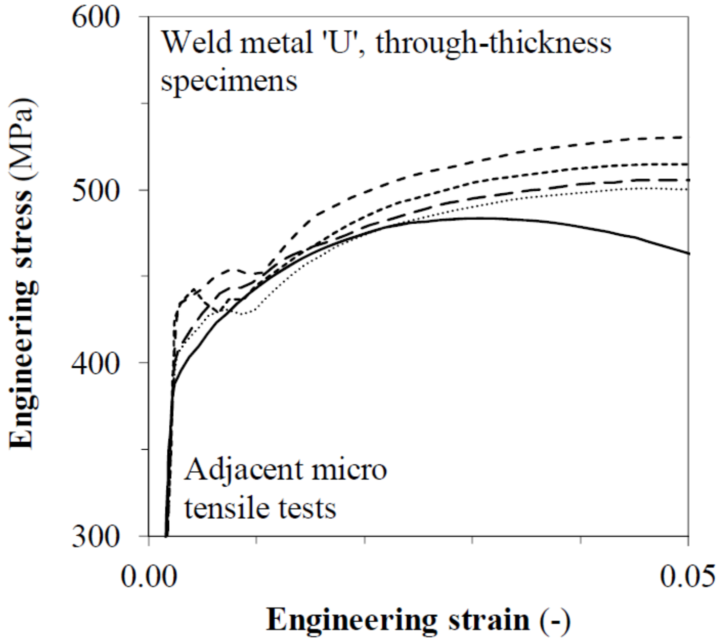
Weld ‘U’,
through-thickness set

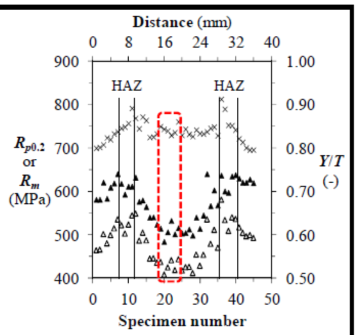
$R_{p0.2}$, R_m, Y/T similar

How about their
strain hardening behaviour?

Stijn Hertelé, Nenad Gubeljak, Wim De Waele
Advanced characterization of weld metal using micro tensile tests
16

Strain hardening behaviour strongly change over a short distance

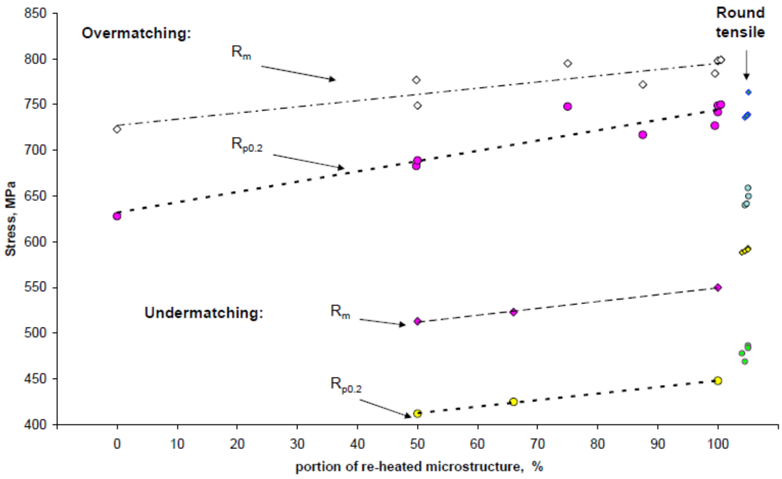




Micro tensile tests & how to analyze them

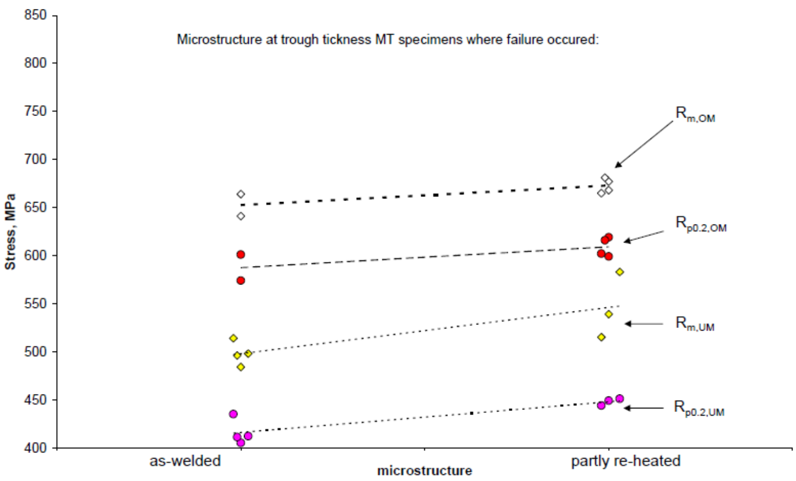
Test material and method	Two FCAW welds in HSLA steel Micro tensile testing program
Heterogeneity of strength	Strength variations up to 100 MPa in 5 mm FITNET upper bound Y/T relation is respected Grain refinement increases strength
Heterogeneity of strain hardening	Strong local variations of strain hardening UGent stress-strain model Two-stage strain hardening for higher Y/T

Comparisson of tensile results MTS and RT!



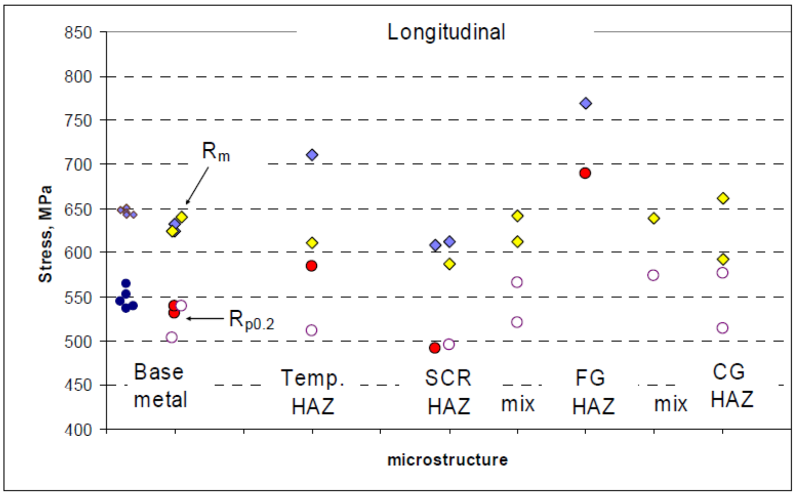
19

Comparisson of tensile results MTS and RT!



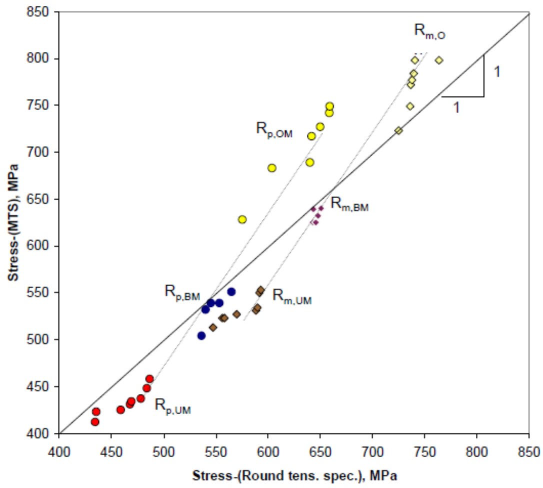
20

Comparisson of tensile results MTS and RT!



21

Comparisson of tensile results MTS and RT!



22

Conclusions

For through thickness specimens faiure occurred in microstructure with lowest tensile strength. It is usually as-welded or partly re-heated weld metal microstructure.

Welding by melting of parent metal has a direct effect on the distribution of HAZ microstructures. Consequently, during the tests, yield sy, ultimate tensile strength Rm through thickness and also elongation has been measured.

Distribution of the tensile properties in the longitudinal direction is more uniform than in through thickness direction.

Also in undermatching (UM) case the tensile properties are quite uniform. In case of overmatching (OM) the effect is opposite. Reason is fact that longitudinal direction two or several microstructures can be contributed to higher or lower strength of weld metal.

23

Conclusions

The difference between strength of as-welded and re-heated microstructure is more significant in OM than in UM weld metal.

Portion of the specified microstructures along the length of the specimen increases (re-heated) or decreases (as-welded) the strength and elongation of weld metal.

Comparison between round tensile (RT) and mini tensile (MT) specimens does not show uniform correlation, but the values depends also on the strength level of material.

Micro-hardness test shows correlation between distribution of microstructure and hardness. Micro-hardness values depend on load level, time and error of measurments (+/- 15HV).

Hence, the micro-hardness measurements in the multiphases weld joint can depict strength (mis-matching) difference, but not accurate values of mechanical properties.

24

LABORATORY SOETE

UNIVERSITY OF MARIBOR

http://www.soetelaboratory.ugent.be
http://www.fs.uni-mb.si

Stijn Hertelé, Nenad Gubeljak, Wim De Waele

Advanced characterization of weld metal using micro tensile tests

25