# Standards related to welding of duplex stainless steels

Ravi Vishnu
Avesta Research centre
Outokumpu

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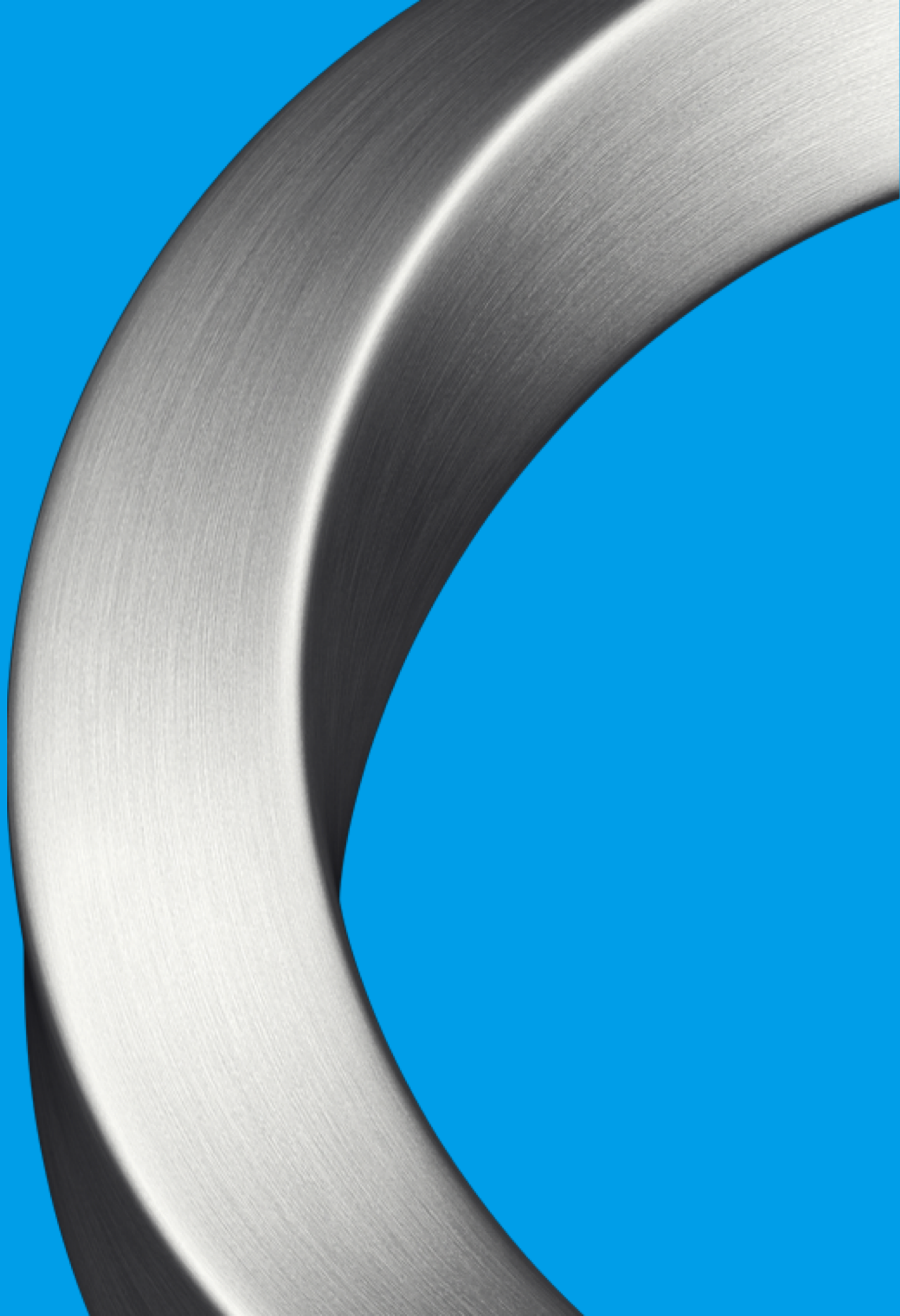


# Outline

- **Comparison of different international standards**
  - **Microstructure**
    - » **Phase balance (Ferrite content)**
    - » **Intermetallics**
    - » **Nitrides**
  - **Stress relief**
- **Conclusions**
  - Mechanical Properties
    - » Impact testing
    - » Transverse tensile test
    - » Hardness testing
  - Pitting Corrosion Testing
    - » ASTM G48 (immersion test in FeCl3 with optional addition of Hcl)
    - » ASTM G150 (Avesta cell)
  - Intergranular corrosion testing
- Welding Procedure Qualification
- Welding recommendations

# Allowed Ferrite content by different standards

| Standard | Appli-cation | Allowed Ferrite (%) | | |
|---|---|---|---|---|
| | | BM | HAZ | Weld |
| ISO 17781 | Petro-chemical | 35-60 | | 30-70 |
| ISO 1516-3 (NACE) | Oil & Gas | | | 30-70 |
| API 938C (API) | Oil Refining | 30-65 | 40-65 | 25-60 |
| M-630 | Offshore Piping | 35-55 | | 35-65 |
| M-601 | Piping Welds | | | 30-70 |
| EN 13445-4 | Pressure Vessels | | 30-70 2d from FL : <85% | 30-70 |

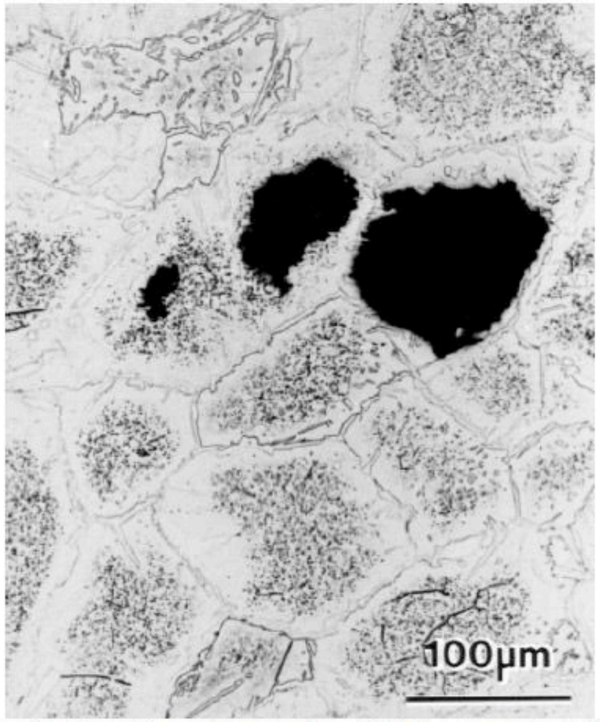
# What is the origin of the 30-70% requirement?

- Is there a scientific basis for this requirement?
- Is there a scientific basis for the difference in the requirements between the different standards
- Does it depend on the different application areas

  (i.e. petrochemical, oil and gas etc.)

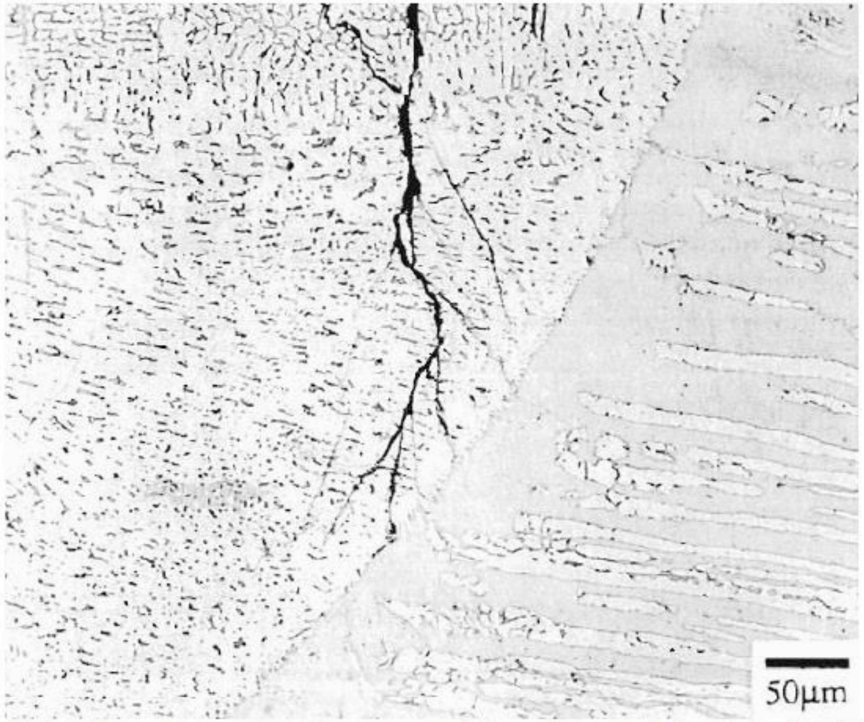
## Illustration of possible consequences of extremely unbalanced duplex microstructures

**90% ferrite**




(a) Pitting in ferrite when too little austenite (<10%) is present so extensive nitride precipitation occurs in the ferrite [3]

**10% ferrite**




(b) Stress corrosion cracking in weld metal with >90% austenite stops at the ferritic HAZ [4]

# What is the origin of the 30-70% requirement?
# Understanding the effect of ferrite Content

Increase in wt% Cr → Increase in ferrite %

will increase CR if nitrides are absent

Can decrease, but influenced by the effect of chemical composition of phases

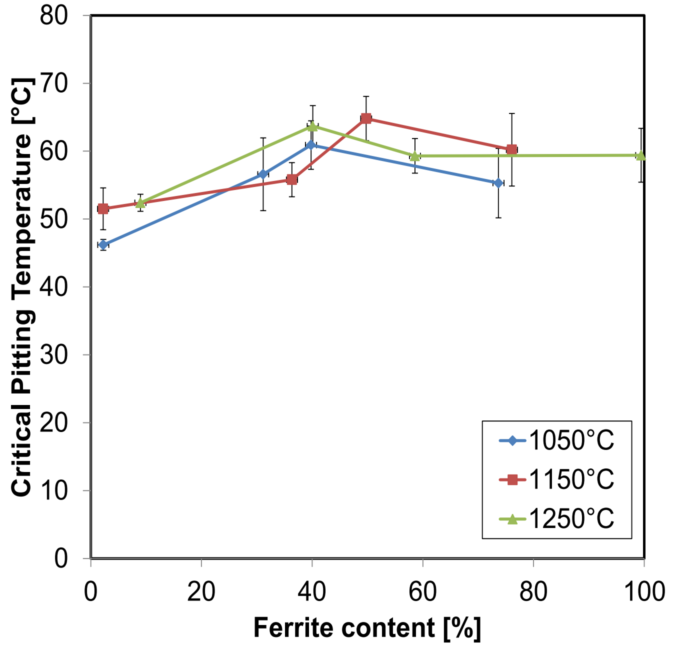
Corrosion resistance

**Confounding effects**
**Difficult to separate the effect of ferrite content alone**

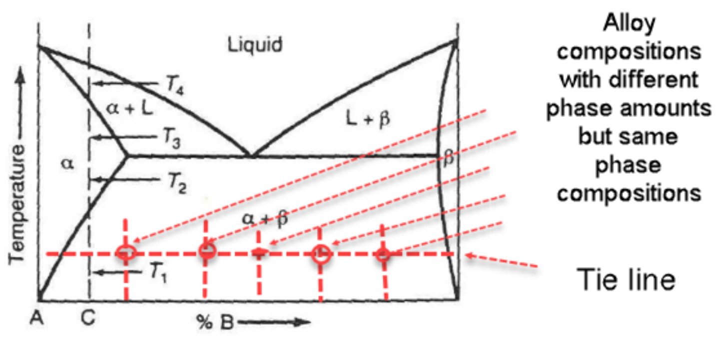
# Evidence for the absence of a ”per se” effect of ferrite content

**Specially tailored alloy compositions with different ferrite contents but same compositions of the ferrite and austenite phases**

**Corrosion resistance of several multicomponent tie line alloys (2205)**




**Explanation of tie line for a binary alloy system**



## What could be the possible reason for a specification of 25-60% ferrite in API 938C?

Fire at ConocoPhillips Refinery

**Duplex 2205 REAC Header Box Cracking**

"Failure was due to sulfide stress cracking, which initiated at a high ferrite, high hardness weld root and followed the fusion line of a weld joining the header box top plate to the plug sheet."

**REAC – Reactor Effluent Air Cooler**

Leaks at duplex welds caused vapour leaks and explosion / fire

In many cases, there was a specification, but it was not adequate to prevent out-of-specification welds

# 30 -70% ferrite - Are they ”soft” or ”hard” limits?

Should the mean and 95% confidence limits be in the 30-70% range?
For impact testing, EN ISO 15614:2017 says:

The average value of the three specimens shall meet the specified requirements. For each notch location, one individual value may be below the minimum average value specified, provided that it is not less than 70 % of that value.

An excerpt from EN 13445-4:2016:

NOTE 3 The limit deviation on metallographic measurements frequently are of the order of ± 5 %.

Does this mean that the acceptable range is 25-75% in reality?

Required precision : 20% relative accuracy as per ISO 17781:2017.
This is much higher than the 5% above.

To resolve this question, can property tests be performed for borderline ferrite contents?

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# Code reqmts. For Intermetallics

| Standard | Year | Addl. | Requirement |
|---|---|---|---|
| Norsok M630 | 2010 | Base matl.<br>Offshore piping | Free from intermetallics |
| Norsok M630 | 2013 - | “ | Free from *detrimental* intermetallics and precipitates |
| DNV-FS-101 | 2013- | Submarine piping | $\sigma < 0.5\%$; total < 1% |
| ISO 1516-3 | 2015 | Oil & gas | $\sigma < 0.5\%$; total < 1% |
| Norsok M-601 | 2016 | Piping welds | Total < 0.5% |
| ISO 17781 | 2017 | Petrochemical | Max dimension < 10 µm |

ISO 17781:2016

### 5.2.4.2 Acceptance criteria

The following acceptance criteria for intermetallic phases and precipitates shall apply:

a) intermetallic phases

NOTE 1 The negative effect of intermetallic phases on functional properties such as impact toughness and corrosion resistance properties is documented in numerous publications and is commonly recognized. Quantification of intermetallic phases requires a large number of fields to give the needed level of confidence and is not considered practical for use in quality control tests. Acceptance criteria are therefore based upon counting the number of discrete intermetallic particles within a number of randomly chosen fields.

The microstructure shall be free from intermetallic phases. The microstructure for base material and products with welds in the solution annealed condition is regarded as "free from" if the following criteria are met:

— the average number of discrete/stand-alone intermetallic particles over a total of 10 randomly chosen fields of view is maximum five (5), and

— the diameter of the discrete intermetallic particles shall not exceed 10 μm.

In case centreline intermetallic stringers are present, this shall be reported and acceptance of the product shall be based upon CVN and corrosion test results.

For welds tested in the as welded condition the microstructure shall be free from intermetallic phases. Alternatively, the acceptance criteria of ISO 15156-3 [3] shall be complied with. The microstructure is regarded as "free from" if the following criteria are met:

— the mean number of discrete/stand-alone intermetallic particles over a total of 10 randomly chosen fields of view is maximum 10, and

— the largest diameter of the discrete intermetallic particles is less than 10 μm.

b) precipitates

If carbide or nitride precipitates are observed the findings shall be reported and documented, and the acceptance shall be based upon the corrosion and CVN impact toughness test, see Table 2 and 5.5.

ISO 17781:2017

No differentiation between as-welded and solution annealed

### 5.2.4.2 Acceptance criteria

The following acceptance criteria for intermetallic phases and precipitates shall apply.

a) intermetallic phases

The microstructure shall basically be free from intermetallic precipitates. However, discrete/stand-alone intermetallic precipitates can be tolerated provided these are located in isolated areas and not homogeneously distributed throughout the test specimen, and that the maximum dimension of each precipitate does not exceed 10 µm.

Micrographs included in Figure 2 are showing examples of microstructures representative of wrought and cast products containing such isolated areas with intermetallic precipitates to a level that can be considered borderline acceptable.

In case centreline intermetallic stringers are present, this shall be reported and acceptance of the product shall be based upon CVN and corrosion test results.

For welds tested in the as welded condition, the microstructure shall be free from intermetallic phases. Discrete/stand-alone intermetallic particles are acceptable given the maximum dimension of these is ≤10 µm, alternatively, the acceptance criteria of ISO 15156-3 shall apply.

b) non-metallic precipitates

If carbide or nitride precipitates are observed, the findings shall be reported and documented, and the acceptance shall be based upon the corrosion and CVN impact toughness test (see Table 2 and 5.5).

# Hydrogen Induced Stress Cracking (HISC)
# ISO 17781:2017
# Influence of nitrides

NOTE Nitrides precipitate along grain boundaries and within the ferrite phase (see References [5], [6], [7] and [8]). Such precipitation can decrease resistance to hydrogen embrittlement in components under cathodic protection. Avoidance of hydrogen embrittlement subsea is principally achieved by appropriate design to limit service stresses/strains (see DNV/GL RP-F112[4]), but excessive nitride precipitation is to be avoided. While determination of the nitride phase balance is impractical, the presence of nitrides in the ferrite phase reduces the CVN impact toughness property, increases micro hardness in the ferrite phase and reduces the breakthrough pitting corrosion potential (see Reference [7]). Quality control to avoid excessive nitrides is therefore best achieved by meeting the impact and corrosion properties given in this specification and applying appropriate design criteria where hydrogen embrittlement is a credible threat (see DNV/GL RP-F112[4]).

- **Nitride precipitation can decrease resistance to hydrogen embrittlement in components under cathodic precipitation.**
- **Quantitative determination of nitrides is impractical.**
- **Suitable design to limit service stresses and strains.**
- **Quality control best achieved by meeting impact and corrosion properties in the spec.**

# Little known tip in EN 10028-7:2016 (pleasant surprise) for Stress Relieving of Weldments

**For carbon and alloy steels, post weld stress relief is done by heating in a furnace to a temperature of about 600°C. For duplex stainless steels, they would have to be heated to a temperaure between 1000 – 1100°C.**

**B.4** Preheating of austenitic-ferritic steels is a very effective precaution against stress increase by shrinkage of thicker welded cross-sections, because temperatures of 200 °C to 250 °C bring down room temperature yield strength by about 50 %. Thus preheating is often more appropriate to avoid high stress levels in those weldments than any post weld heat treatment, and a preheating temperature between 120 °C and 200 °C according to the particular steel and thickness should be applied.

**Usually, max interpass temperature is 100 - 150°C**

**Preheating to about 200ºC! – Partial stress relief**

**Reason: $\sigma_{Rp0.2}$ about 50-70% of that at room temperature**

**But this will require much lower heat inputs than normal.**

**Plus, special procedure qualification necessary**

# Conclusions

- An important aspect of duplex standards is that they attempt to base the requirements on the microstructure.
- In principle, this is right because the properties are dependant on the microstructure.
- But the microstructure-properties relationship is an inexact one.
- There is considerable uncertainty in the quantitative measurement of microstructural features.
- This explains the fuzziness of the requirements in the standards and in the differences between them.
- We should actively cooperate in working together (research institutes, universities and industry) in sharing data and identifying significant questions which require clarifications. The Duweltool project is one milestone activity on this path.
- Aim for the future – further develop the app to be able to satisfy many of the requirements in the standards.