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# DUPLEX STAINLESS STEELS

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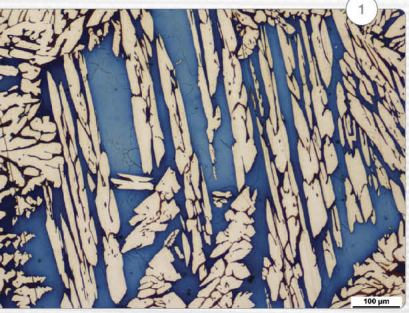
## INTRODUCTION

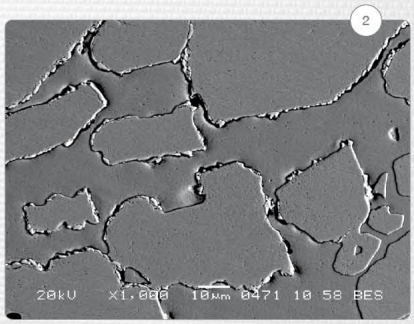
Duplex or ferritic-austenitic stainless steels have a history almost as long as stainless steels. Duplex stainless steels (DSSs) are based on the Fe-Cr-Ni system and formed by ferrite (30–70 %) and austenite. DSSs are used for several applications in oil, gas, paper and petrochemical industries due to their attractive combinations of good mechanical properties and high corrosion resistance. Duplex steels have a resistance to general corrosion similar to the austenitic stainless steels but much higher mechanical strength, in part due to an addition of about 0.15% of nitrogen.

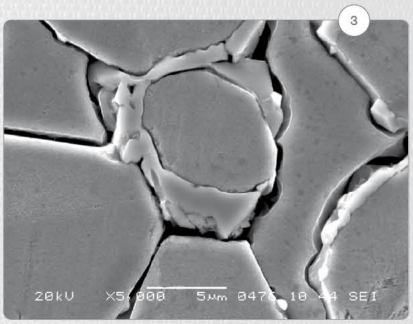
The processes conduct at high temperatures, such as forging, extrusion or rolling, are critical for the DSSs due to the precipitation of detrimental phases. Sigma phase precipitates at temperatures below austenite formation from the ferrite on cooling. Sigma phase precipitates through the diffusion of chromium and molybdenum from the delta ferrite to the ferrite/austenite interfaces. The δ/γ interface with high interfacial energy is considered the most favourable site for precipitation of this intermetallic phase.

## MICROGRAPHS OF CAST STATE

Investigated surface was etched by Beraha solution for microstructure observation. Local chemical composition was monitored by EDX analyzer INCAx-sight. Quantitative image analysis of micrographs of specimens was performed by means of NIS Elements software. NIS Elements software is a powerful toll for measuring (among others) exact area i.e. volume fraction of inspected phase. Results from the image analyses proved ~50% ferrite and 50 % austenite. Sigma precipitation occurs at δ/γ interface of cast state (example see Figure).



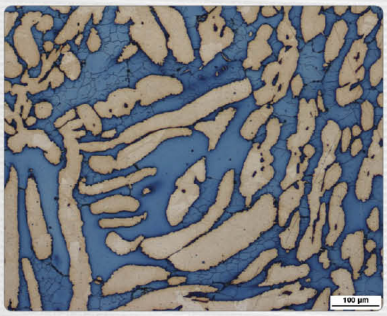

1. Quantitative image analysis of cast state micrographs, 100×
2. Sigma phase of cast state, 1000×
3. Sigma phase of cast state, 5000×

## METALLOGRAPHY FROM FINAL FORGING

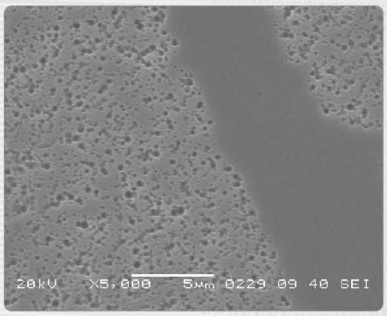
Results from the image analyses proved ~46 % ferrite, 54 % austenite. Different type of cooling from final forging (see Table) has influence on presence of sigma phase precipitates, which were also observed with SEM JEOL JSM 6380 (see Figure).

| Sample | Dwell at forging temperature | Forging from 1200°C to 900°C / cooling |
|---|---|---|
| 1 | 10 hours | from final forging temperature water cooled |
| 2 | 10 hours | air cooled |

» Investigated surface was electroetched by 20% NaOH solution for sigma phase observation
» Twenty image fields were evaluated for final volume fraction of sigma phase
» Results from the image analyses proved ~5% sigma phase



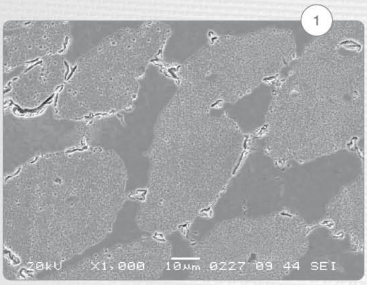

Quantitative image analysis of sample 1 micrographs, 100×

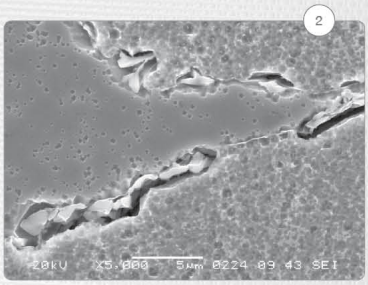


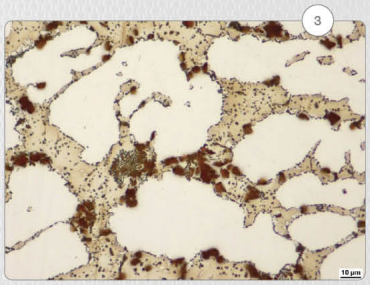

Sigma phase analysis sample 1, 5000× Microstructure without sigma phase

## CONCLUSION

» Sigma phase plays significant role in duplex stainless steels heat treatment and especially during forming processes
» Different type of cooling from final forging has influence on presence of sigma phase precipitates
» Metallographic analyses provide important information of duplex stainless steels development




1. Sigma phase analysis sample 2, 1000× Sigma phase at inerfaces δ/γ
2. Sigma phase analysis sample 2, 5000× Sigma phase at inerfaces δ/γ
3. Light microscope, sample 2, 500× Quantitative image analysis of sigma phase

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