The structural stability of creep resistant austenitic steels SUPER 304H and Tp 347HFG

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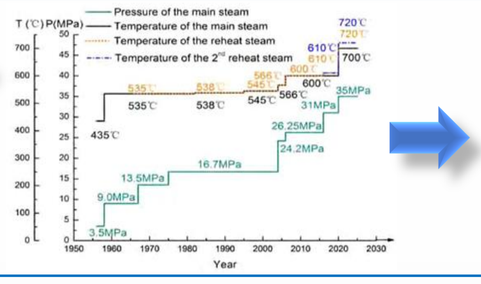
Field of study: Materials engineering

Motivation

Upgoing of steam working parameters



Necessary of new modern materials application
For those materials aren´t well documented properties under exposition

Model microstructural changes

- Increase of complex efficiency to 47 % (average subcritical boiler efficiency is about 37 %)
- Money save for coal per year will be 16,4 mil. $ (that is equal with 330 mil. $ save during of all the power plant lifetime)
- The drop of CO_2 emission is by 22% (700 000 ton CO_2/year)

Thesis goals

- Describe sigma phase precipitation processes for steel SUPER 304H and perform their general mathematical description
- Model precipitation kinetics processes based on chemical composition and physical laws like modification of the steel Tp 347HFG
- Correlate model with measured particles after the long-term heat exposition for steel Tp 347HFG
- Find and describe the kinetic function of the sigma phase precipitation for the steel SUPER 304H

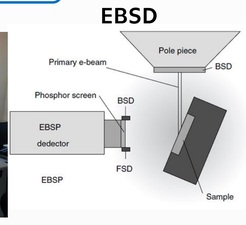
Methodology

Heat exposition

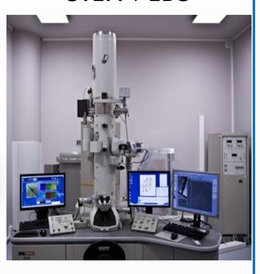
Optical microscopy

SEM + EDS

EBSD



STEM + EDS

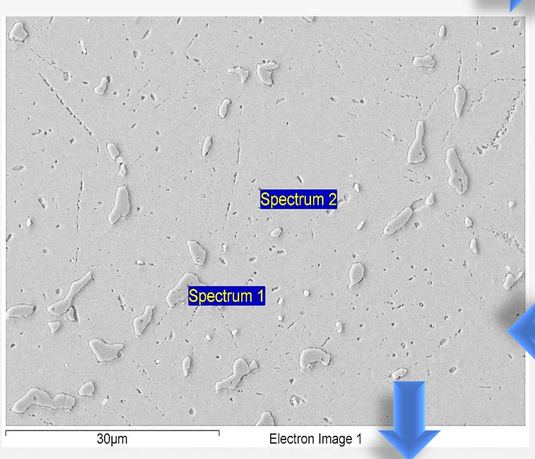


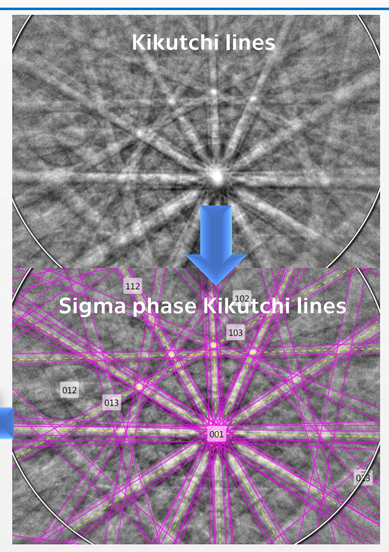
Experimental material

	C	Si	Mn	P	S	Cu	Cr	Ni	Nb	B	N	Al
Min. (ASME Case 2328-1)	0,07	-	-	-	-	2,50	17,0	7,5	0,30	0,001	0,05	0,003
Max. (ASME Case 2328-1)	0,13	0,30	1,00	0,04	0,01	3,50	19,0	10,5	0,60	0,010	0,12	0,030
SUPER 304H F124139	0,08	0,25	0,81	0,003	0	3,07	18,3	9,0	0,49	0,004	0,11	0,005

Experiments

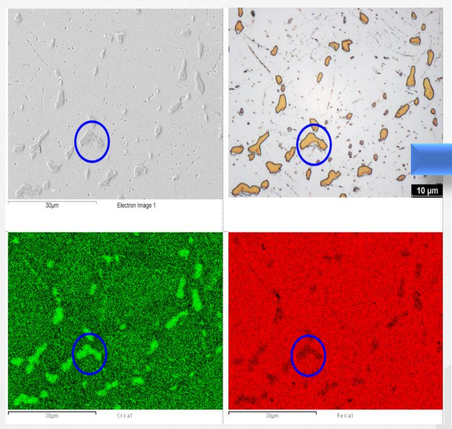
Phase identification



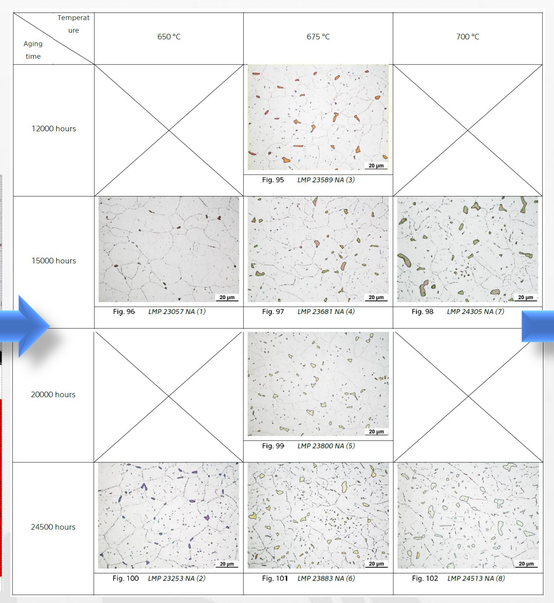


Spectrum	Si	P	Ca	Cr	Fe	Ni	Cu	Nb	Mo	W
Spectrum 1	0.97	0.46	0.35	36.29	56.27	3.33			1.98	0.35
Spectrum 2	0.37			18.84	66.95	8.80	4.54	0.15	0.35	

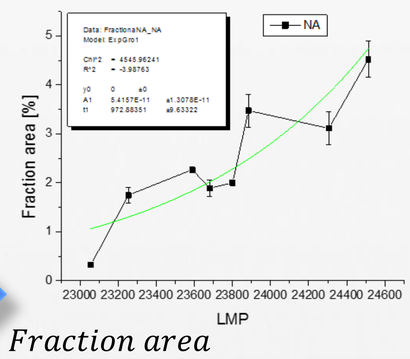
Extension for optical microscopy



Quantification



Mathematical description



$$Fraction\ area = 5{,}42 * 10^{-11} * e^{\left({}^{LMP}/_{972{,}88}\right)}$$

$$Precipitation\ rate = 5{,}57 * 10^{-14} * e^{\left({}^{LMP}/_{972{,}88}\right)}$$

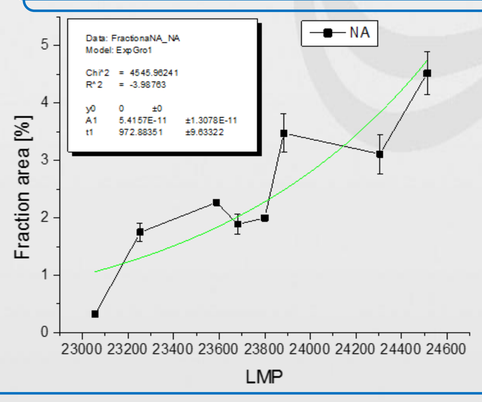
- Sigma phase was confirmed by SEM, STEM, EBSD and by Kikutchi lines
- Results from electron microscopy was extended for optical microscopy
- Quantification and description was based on optical microscopy, color etching
- Modeling was based on mathematical background

$$\frac{\partial c_k}{\partial \tau} = D_{kl}\frac{\partial^2 c_k}{\partial^2 z} \qquad D = D_0 exp\left(-\frac{Q_d}{RT}\right)$$

$$c_k = f(z,\tau)$$

$$\frac{c - c_0}{c_1 - c_0} = 1 - erf\left[\frac{x}{2(D\tau)^{1/2}}\right] \qquad c = (c_0 - c_1)erf\left[\frac{x}{2(D\tau)^{1/2}}\right] + c_1$$

Results discussion



Tp 347HFG	
Time/Temperature	
973,15/10000 [K/Hours]	
Sample	Fraction area
1	0,023
2	0,027
3	0,027
4	0,032
5	0,032
Average	0,0282

SUPER 304H	Tp 347HFG	Tp 347HFG
Calculated	Calculated	Measured
3,24	2,94	2,82

Reached difference between measured and modeled sigma phase content was 0,06% (absolute value of error is 4,08%)

Reaching thesis goals

- *Describe sigma phase precipitation processes for steel SUPER 304H and perform their general mathematical description*

The precipitation processes were described through the sigma phase fraction area. Mathematical description of the sigma phase precipitation was made by exponential growth function.

- *Model precipitation kinetics processes based on chemical composition and physical laws like modification of the steel Tp 347HFG*

The sigma phase modelling was based on measured values for SUPER 304H and modification coefficients. Modification coefficients were calculated according Fick laws and Larson-Miller construction. Through application of modification coefficients (which describe chemical composition and LMP differences) sigma phase fraction area for steel Tp 347HFG was calculated.

- *Correlate model with measured particles after the long-term heat exposition for steel Tp 347HFG*

Correlation was performed for available degraded samples of Tp 3247HFG after exposition 700°C for 10 000 hours. Difference between calculated values (based on coefficient modification) and real measured sigma phase fraction area was 4,08 %. This difference confirms applicability of coefficient modification methodology.

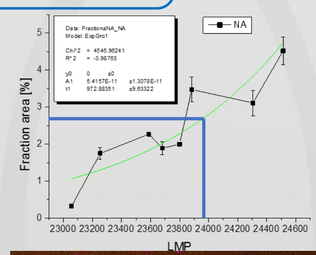
- *Find and describe the kinetic function of the sigma phase precipitation for the steel SUPER 304H*

The sigma phase kinetic function was described like time derivation of the fraction area exponential growth function.

Practical application and proposals for future

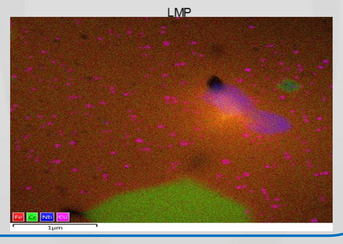
Application

- Degradation prediction
- State of degradation
- Model application for developing new alloy



Proposals

- Develop heat treatment for sigma phase dissolving
- Influence of Cu nano particles



Author´s publications linked with Thesis

Impact and WoS publications

1. HORVÁTH, Jakub, Petr KRÁL a Jiří JANOVEC. The Effect of Sigma-Phase Formation on Long-Term Durability of Welding Joints in SUPER 304H Steels. *Acta Physica Polonica A*. Warsaw, 2016, 130(4), 960-962. ISSN 0587-4246. [52]
2. HORVÁTH, Jakub, Michal JUNEK a Jiří JANOVEC. The Changes in Mechanical Properties of Austenitic Creep Resistant Steels SUPER 304H and HR3C Caused by Medium-term Isothermal Ageing. *Solid State Phenomena*. 2017, 258, 639-642. ISSN 1012-0394. [54]
3. HORVÁTH, Jakub, Petr KRÁL, Jiří JANOVEC a Václav SKLENIČKA. THE EFFECT OF SIGMA-PHASE FORMATION ON LONG-TERM DURABILITY OF SUPER 304H STEEL. *METAL 2015: 24TH INTERNATIONAL CONFERENCE ON METALLURGY AND MATERIALS*. Brno, CZECH REPUBLIC: Tanger, 2015, s. 505-510. ISBN 978-80-87294-62-8. [53]
4. HERMANOVÁ, Šárka, Ladislav KANDER a Jakub HORVÁTH. The Effect of Cold Bending Process and Degradation at Boiler Conditions on the Properties of New Austenitic Creep Resistant Steel SUPER 304H for Boiler Super-heaters Tubes. *Materials Science Forum*. 2017, (891), 230-234. ISSN 0255-5476. [50]
5. HORVÁTH, Jakub. The influence of high temperature overheating to microstructure of degraded steel SUPER 304H. *METAL 2018: 27TH INTERNATIONAL CONFERENCE ON METALLURGY AND MATERIALS*. Brno, CZECH REPUBLIC: Tanger, 2018 (Under review)

Indexed and other publications

1. HORVÁTH, Jakub, Jiří JANOVEC a Marie SVOBODOVÁ. Impact of plastic deformation on thermal induced structural changes in HR3C steel. In: *Zvyšování životnosti komponent energetických zařízení v elektrárnách: Sborník z 9. konference. Plzeň*: ZČU, 2014, s. 153-158. ISBN 978802614063. [49]
2. HORVÁTH, Jakub, Petr KRÁL, Jiří JANOVEC a Václav SKLENIČKA. THE EFFECT OF SIGMA-PHASE FORMATION ON LONG-TERM DURABILITY OF SUPER 304H STEEL. In: *Metal 2015: 24th International conference on Metallurgy and materials*. Ostrava: Tanger, 2015, s. 57-58. ISBN 978-80-87294-58-1.
3. HERMANOVÁ, Šárka, Radomír ČINČILA, Jakub HORVÁTH a Jiří JANOVEC. INFLUENCE OF COLD BENDING OF STRUCTURAL STABILITY OF USC OUTLET SUPERHEATER MADE FROM AUSTENITIC CREEP RESISTANT STEELS In: *Zvyšování životnosti komponent energetických zařízení v elektrárnách: Sborník z 10, konference*. Plzeň: Západočeská univezita v Plzni, 2015, s. 89-92. ISBN 978-80-261-0522-0. [51]
4. HORVÁTH, Jakub, Petr KRÁL, Jiří JANOVEC a Václav SKLENIČKA. The Effect of Microstructure Changes of Steel SUPER 304H during Laboratory Thermal Exposition. in: *Functionalized Nanostructures Towards Engineered Macrostructures*. 1. Jindřichův hradec: Epika, 2015, s. 131-141. ISBN 978-80-88113-20-1.
5. HORVÁTH, Jakub, Michal JUNEK a Jiří JANOVEC. The Changes in Mechanical Properties of Austenitic Creep Resistant Steels SUPER 304H and HR3C Caused by Medium-term Isothermal Ageing. In: *Materials structure a micromechanics of fracture: Abstrat booklet*. Brno: VUTIUM, 2016, s. 216. ISBN 978-80-214-5357-9.
6. HORVÁTH, Jakub, Jiří JANOVEC a Ladislav HORVÁTH. *VLIV LABORATORNÍ TEPLOTNÍ EXPOZICE NA ZPŮSOB MECHANICKÉHO PORUŠOVÁNÍ AUSTENITICKÉ OCELE HR3C*. Sborník příspěvků z 12. konference "Zvyšování životnosti komponent energetických zařízení v elektrárnách": Plzeň: Západočeská universita, 2017, 151-154. ISBN 978-80-261-0741-5.