Microstructural analysis of austenitic heat resistant steel modified with silicon

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The austenitic heat resistant steel with modified silicon concentration can be used in turbocharger technology, where heat and oxidation resistance, dimensional stability as well as high ductility of material are required. Below 1000 °C the austenitic stainless steel with 25 % Cr and 20 % Ni consists of two phases i.e. austenite ( ) and sigma phase (σ). The fully austenitic material is therefore unstable and during the exposure at elevated temperature σ phase can be formed. The formation of σ is usually preceded by carbide precipitation. The kinetics of formation of σ phase depends on a number of factors including temperature, carbon content, solution treatment temperature, degree of prior cold work and chemical composition.[1-3] Since sigma phase is hard and very brittle and therefore detrimental it is necessary to investigate the microstructure and estimate the portion of sigma phase. For the examination of the microstructure a light microscope and scanning electron microscope (SEM) equipped with energy dispersive x-ray spectrometer were used.

Three different samples from austenitic heat resistant steel modified with silicon were investigated, namely as-received, annealed at 800 °C for 4 hours and additionally annealed samples at 1000 °C for 4. After annealing both samples were cooled in the air. The annealing temperatures were chosen to accelerate the formation of sigma phase since they were higher than operating temperature of turbocharger part. The investigated material showed dendritic microstructure with large austenite grains. The estimated grain size G was below 1. The microstructural analysis of as-received sample revealed the continuous carbide phase precipitated on the grain boundaries, while the interior of crystal grains was free of carbide precipitates. EDS analysis also confirmed three types of inclusions, namely MnS, TiN and Al2O3.

After first annealing at 800 °C/4h the grain size remains practically unchanged (G < 1).The austenite grain boundaries are even more marked with carbide phase. SEM revealed the areas where the carbides are piled up around some nonmetallic inclusions and in the interior of the austenite grains as well as along the grain boundaries of the austenite grains. However, in this sample also sigma phase on the grain boundaries as well as in the shape of loops was detected (**Figure 1**).

After additional annealing at 1000 °C for 4 hours no significant change in the microstructure was observed. The amount of carbide phase on grain boundaries is slightly increased. However, the carbides precipitates are still piled up around some nonmetallic inclusions, sigma phase and along grain boundaries as well. Based on the microstructure examination the portion of sigma phase in the samples was practically unchanged in comparison to the previous ample annealed at 800 °C and it was estimated to be less than 2%. EDS maps of sigma phase and EDS point analysis confirms that sigma phase is enriched in Cr and depleted in Fe and Ni. Since a lot of chromium carbide precipitates on grain boundaries of austenite grains or they are pilled up in their vicinity, there is an increased possibility of chromium depletion in the matrix below the level which assure corrosion resistance of steel. Therefore, EDS analysis across grain boundaries along which carbides had

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precipitated was performed in the sample annealed at 820 °C for 50 hours (**Figure 2**). The results of EDS analysis (**Table 1**) confirmed that content of chromium near grain boundaries didn't fell below 22 %. Thus, depletion in chromium in the matrix was not critical.

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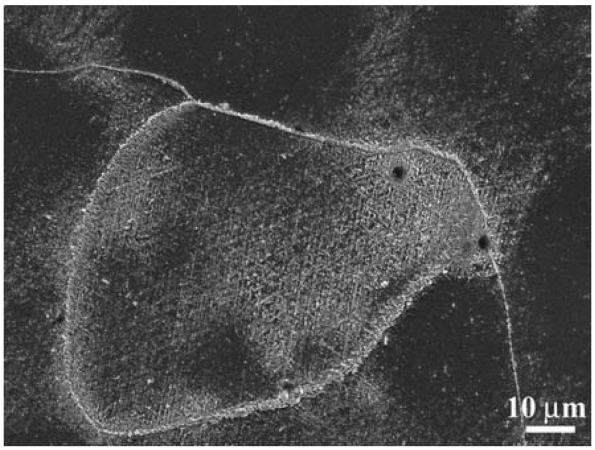

Figure 1. SEI of sigma phase and carbide precipitates in sample annealed at 800 °C/4h

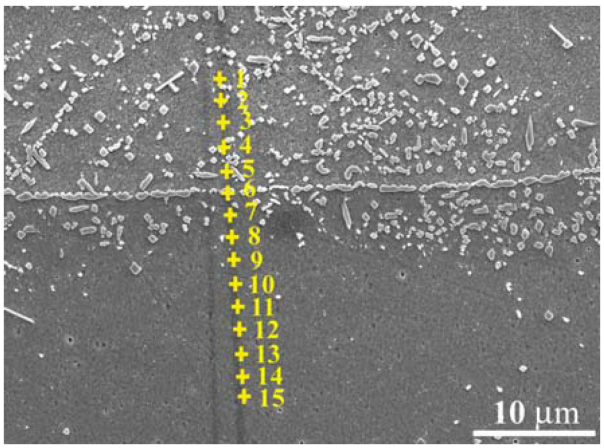

Figure 2. SEI of the microstructure where EDS point analysis across grain boundaries was performed

Table 1: Results of EDS point analysis across grain boundary (according to **Figure 2**)

EDS spot	wt.% Si	wt.% σ	wt.% Cr	wt.% σ	wt. % Fe	wt.% σ	wt.% Ni	wt.% σ
1	0.58	0,11	25.79	0,40	53.49	0,54	20.14	0,55
2	0.42	0,11	30.17	0,42	49.44	0,53	19.97	0,54
3	0.56	0,10	23.32	0,38	55.21	0,54	20.90	0,55
4	0.46	0,10	26.39	0,41	53.41	0,54	19.75	0,55
5	0.47	0,11	43.46	0,50	41.42	0,52	14.65	0,52
6	0.55	0,11	38.33	0,49	45.28	0,54	15.84	0,55
7	0.44	0,10	22.16	0,38	56.17	0,54	21.22	0,55
8	0.42	0,10	24.28	0,39	55.41	0,54	19.89	0,55
9	0.46	0,10	23.58	0,38	55.27	0,54	20.70	0,54
10	0.46	0,11	24.04	0,39	54.92	0,54	20.58	0,55
11	0.48	0,11	24.81	0,40	54.81	0,54	19.91	0,55
12	0.57	0,10	24.59	0,39	54.67	0,54	20.17	0,54
13	0.41	0,10	24.13	0,39	55.54	0,54	19.92	0,55
14	0.46	0,10	24.23	0,39	55.68	0,55	19.64	0,55
15	0.49	0,10	24.06	0,39	56.13	0,55	19.31	0,55

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