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Effect of heat treatment on the microstructure evolution of HP40 heat-resistant steel

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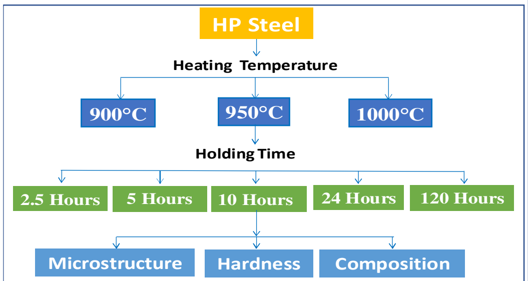
Introduction

In this study, the effect of heat treatment on the microstructure evolution of HP heat-resisting steel (25%Cr-35%Ni-1%Nb) was investigated. The temperature was controlled at 900°C-1000°C for 2.5-120 hours, and the microstructures were observed under different heat treatment conditions, the composition of the precipitate, as well as its mechanical properties can be detected.

A partial transformation of the primary Niobium Carbide to a Nickel-Niobium-silicide, identified as the G-phase ($Ni_{16}Nb_6Si_7$) at temperatures between 900°C-1000°C in HP steels. This transformation also affects the high-temperature mechanical properties of these alloys.

Experiment Procedures



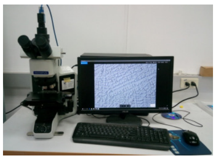
HP Steel Chemical compositions

Alloy Elements (wt.%)	C	Si	Mn	P	S	Ni	Cr	Nb	Fe
HP-Nb	0.30-0.50	1.00-2.50	2	0.04	0.03	33.00-36.00	24.00-27.00	0.80-1.80	Bal.

High Temperature Furnace

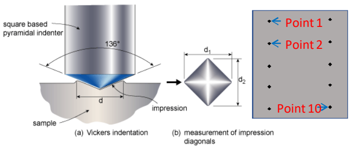
Furnaces are used to achieve a distinct structure when we change the heating temperature and holding time. For this experiment, the specimen was rapidly quenched.

Optical Microscope



Using metallurgical microscope under various magnifications to study of the structure and constitution of phases and alloy matrix, the physical and mechanical properties of an alloy can be related to its observed microstructure.

Hardness Measurement



The measurement of hardness is to evaluate the questioned material's ability to resist plastic deformation from a standard source.

Scanning Electron Microscope (SEM)

SEM is a type of electron microscope that can provide various signals including information about the sample's surface topography (Backscattered-electron imaging-BEI) and chemical composition (Energy-dispersive X-ray spectroscopy-EDS)

SEM Microstructure

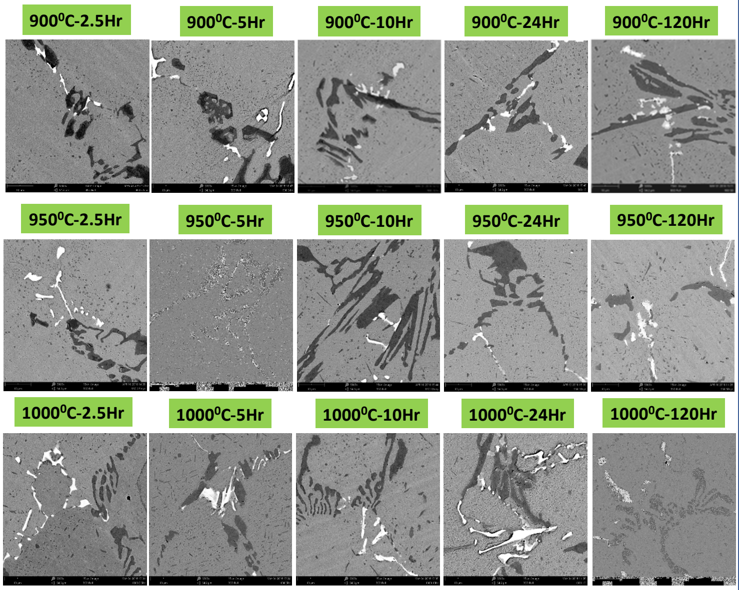


Fig 1: The HP steel SEM microstructure

According to BEI, the dark phases can be identified as chromium-rich, while the Nb-rich phases appear as white regions, due to the atomic contrast of BEI image that Nb has a much greater atomic weight than Cr.

The phase transformation of HP-Nb alloy to secondary chromium carbide precipitates and G-phase has been found after long period holding time employed .

More obviously, the Nb-phases [NbC and G-phase] can be distinguished clearly with the primary and secondary chromium carbide precipitates by BEI.

Hardness

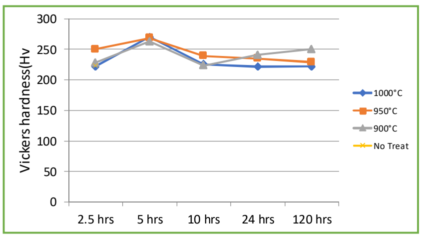
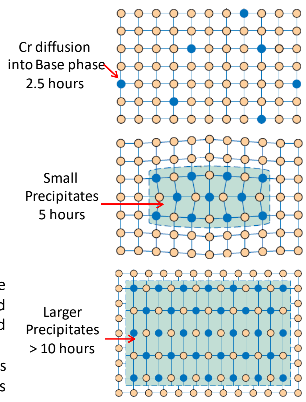


Fig 7: The change of Hardness after heat treatment



❖ When we heat up the HP steel, the precipitates are formed by Cr diffusion into base phase, dispersed precipitates and steel hardness increasing. But by long period heating hardness decrease by precipitates growth.

❖ As increasing holding time, G-phase is formed and grows up replacing Nb-rich phase. The hardness of HP steel is gradually increasing as the formation of G-phase.

EDS Analysis

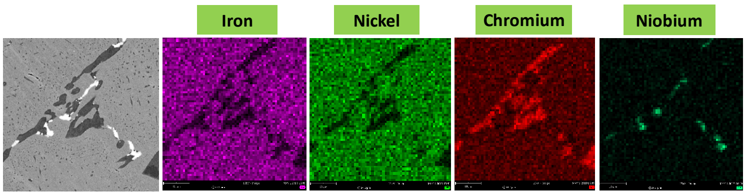


Fig 2: The Elements distribution map

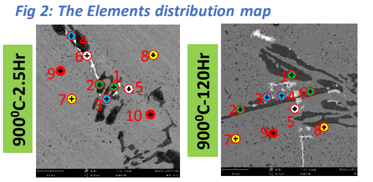


Fig 3: Microstructure at different heating temperature

900°C-2.5Hr

at%	C	Fe	Ni	Cr	Nb	Si
White	86.81	0.91	1.15	1.58	9.77	---
Black	60.05	5.01	1.28	34.19	---	---
G-Phase	54.74	8.92	6.03	39.31	---	---
Base	55.68	16.62	15.36	10.34	---	1.87
Precipitates	53.04	10.97	10.22	23.96	---	1.82

900°C-120Hr

at%	C	Fe	Ni	Cr	Nb	Si
White	87.15	0.73	1.44	1.06	8.99	0.65
Black	74.07	3.10	1.58	21.25	---	---
G-Phase	81.80	1.39	8.57	0.94	3.97	3.32
Base	73.93	10.12	9.11	5.91	---	0.87
Precipitates	73.21	6.90	5.45	13.81	---	0.63

Fig 4: Composition of HP steel at different color

Niobium-rich phase NbC (White phase)

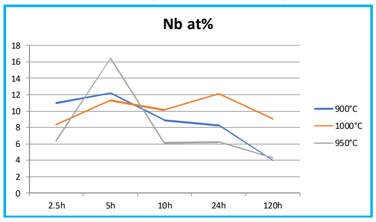


Fig 5: Nb Concentration at different heating time

Chromium-rich phase Cr_7C_3 or $Cr_{23}C_6$ (Dark phase).

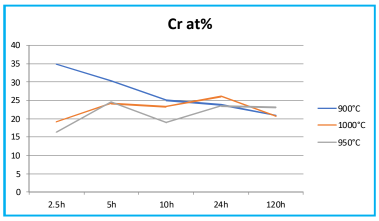


Fig 6: Cr Concentration at different heating time

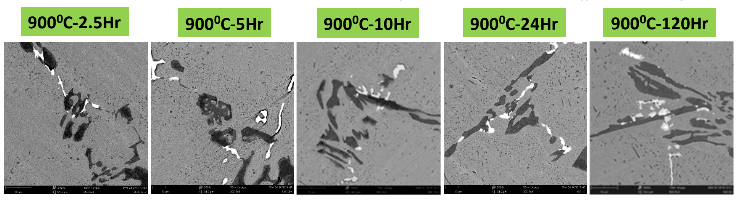
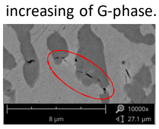


Fig 7: Phase transformation

HP is constituted of an austenite matrix with a niobium-rich phase NbC (White phase) and a chromium-rich phase Cr_7C_3 or $Cr_{23}C_6$ (Dark phase). When we start heating from 900°C-1000°C along period, Cr diffusion out to form the secondary precipitation of $M_{23}C_6$ carbides. During aging of precipitates, NbC phase were transformed to G-phase ($Ni_{16}Nb_6Si_7$) as a consequence of the instability of NbC in this temperature range and combination of Si and Ni diffusion go into NbC phase. It's indicated that White phase decreasing by increasing of G-phase.



G-phase is known that very hard, it is also very brittle. By increasing the hold time, cracks are developed and tend to multiple.

This result indicates that material failed from inside when using it with high temperature and long period.

Conclusions

- From the results of microstructure observation, it can be found that with the passage of time, chromium and niobium will gradually dissolve into the substrate, and a secondary phase of chromium carbide will be generated, and the secondary phase will also gradually become coarse.
- In terms of EDS, the content of niobium will gradually decrease, and it will form a G-phase ($Ni_{16}Nb_6Si_7$) at its boundary. This is an embrittle phase that can increase the hardness of the pipe but it is also most likely to cause brittle fracture of the pipe.