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On the Cobalt – Tungsten/Chromium balance in martensitic creep resistant steels

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introduction

Novel martensitic creep resistant steels strengthened by Laves phase and $M_{23}C_6$ precipitates have been developed in former works. By alloying with a high level of Co, the coarsening kinetics of the conventionally-considered detrimental precipitates can be remarkably improved. In the present work, the characteristics of Laves phase and $M_{23}C_6$, such as volume fraction, coarsening rate and precipitation strengthening factor in the newly designed alloys are compared computationally with the existing Co-containing counterparts. The Co effects on precipitation characteristics are investigated systematically. The alloying elements which are sensitive to Co variations are identified. The binary analyses of Co-M balance show that Co-W are highly coupled in Laves strengthening system and W can partially replace Co to yield the same precipitation strengthening. For the $M_{23}C_6$ strengthened alloy, Cr shows a strong effect by Co and hence a high Co concentration is necessary for a high creep resistance.

Model validation

Translator: Property to microstructure

High strength and high stability $\Rightarrow$ Martensitic matrix + Laves/ $M_{23}C_6$ precipitate

Creator: microstructure to quantifiable criteria

Microstructure

Go/No-go criteria

1. Matrix: Martensite for high strength and stable at high temperature	$M_s > 250^\circ\text{C}$ to obtain martensitic matrix
2. Limited undesirable phases At austenization temperature At ageing/service temperature (such as AlN, Laves phase, MU)	$C_{\text{primary carbide}} < 0.5\%$ no ferrite $C_{\text{undesirable phase}} < 1\%$ $C_{\text{sigma}} < 4\%$
3. Cr_2O_3 , Cr_3O_4 Oxide film At ageing/service temperature	$Cr_{\text{matrix}} > 11\%$ to form Cr_2O_3 , Cr_3O_4 oxide film

Calculated by ThermoCalc

Optimisation: get a best solution from the solutions satisfying all go/no-go criteria

$$\sigma_p \propto 1/L = \sqrt{f_p} / r = \sqrt{f_p} / \sqrt[3]{r_0^3 + Kt}$$

In which

$$r_0 = 2\gamma / \Delta G_v$$

$$K = 8\gamma V_m^p / \sum_{i=1}^n \frac{9(x_i^p - x_i^{mp})^2}{x_i^{mp} D_i / RT}$$

L : inter-particle spacing
 f_p : volume fraction of precipitates
 r_0 : initial size of precipitates
 K : coarsening rate of precipitates

Tab. Composition (in wt.%) of newly designed alloys

	C	Cr	Ni	W	Co	Nb	N	V	Mo	Ti	Al	Taus/ $^\circ\text{C}$
LavesW	0.001	10.84	3.23	10.00	10.00	0.32	0.03	0.001	0.00	0.11	0.001	1239
$M_{23}C_6$ W	0.15	16.00	0.01	1.61	10.00	0.001	0.006	1.00	0.00	0.01	0.001	1069

Results

Compared with existing grades

The effect of Co element

Co-W binary effect in LavesW

Co-Cr binary effect in M23C6W

Conclusion

- ❖ The newly designed alloys remarkably outperform the existing alloys.
- ❖ Co effects: precipitation strengthening contributions inevitably degrade as the Co alloying decreases.
- ❖ In LavesW alloy, Co can be partially replaced by W to yield the same precipitation strengthening level.
- ❖ In $M_{23}C_6$ W alloy, Co plays an irreplaceable role.

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