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

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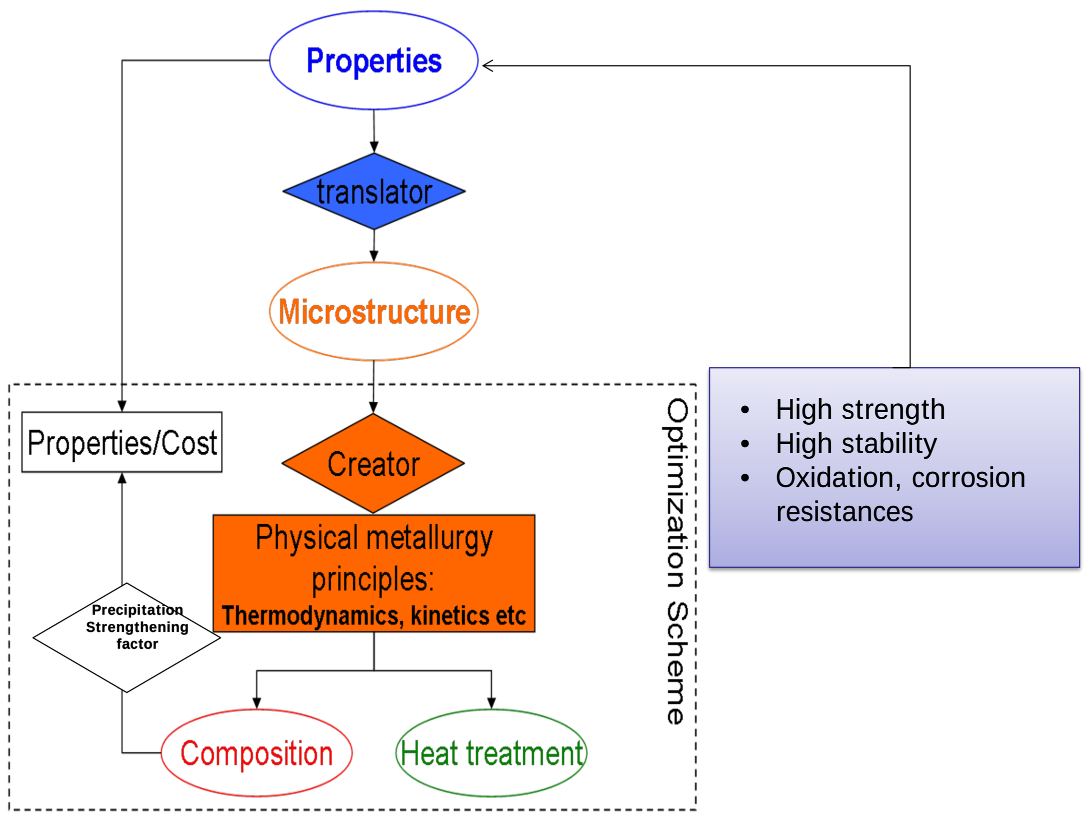
Novel Aerospace Materials

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.

Design Methodology



Model validation

Translator: Property to microstructure

High strength and high stability ⇨ **Martensitic** matrix + **Laves/M23C6** precipitate

Creator: microstructure to quantifiable criteria

Microstructure		Go / No-go criteria
1. Matrix: Martensite for high strength and stable at high temperature	⇨	Ms>250°C to obtain martensitic matrix
2. Limited undesirable phases	⇨	$C_{primary\ carbie}$<0,5% no ferrite
At austenization temperature At ageing/service temperature (such as AlN, Laves phase, MU)	⇨	$C_{undersirable\ phase}$<1% C_{sigma}<4%
3. Cr_2O_3, Cr_3O_4 Oxide film At ageing/service temperature	⇨	Ccr,matirix>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

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

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

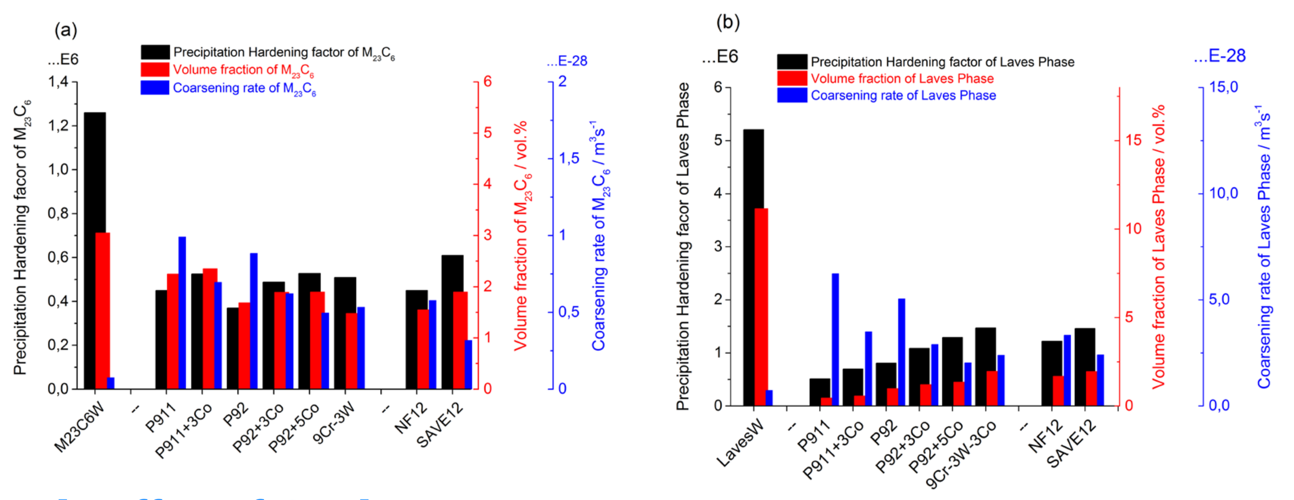
L : inter-particle spacing
f_p: volume fraction of precipitates
r_0: initial size of precipitates
K: coarsening rate of precipitates

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

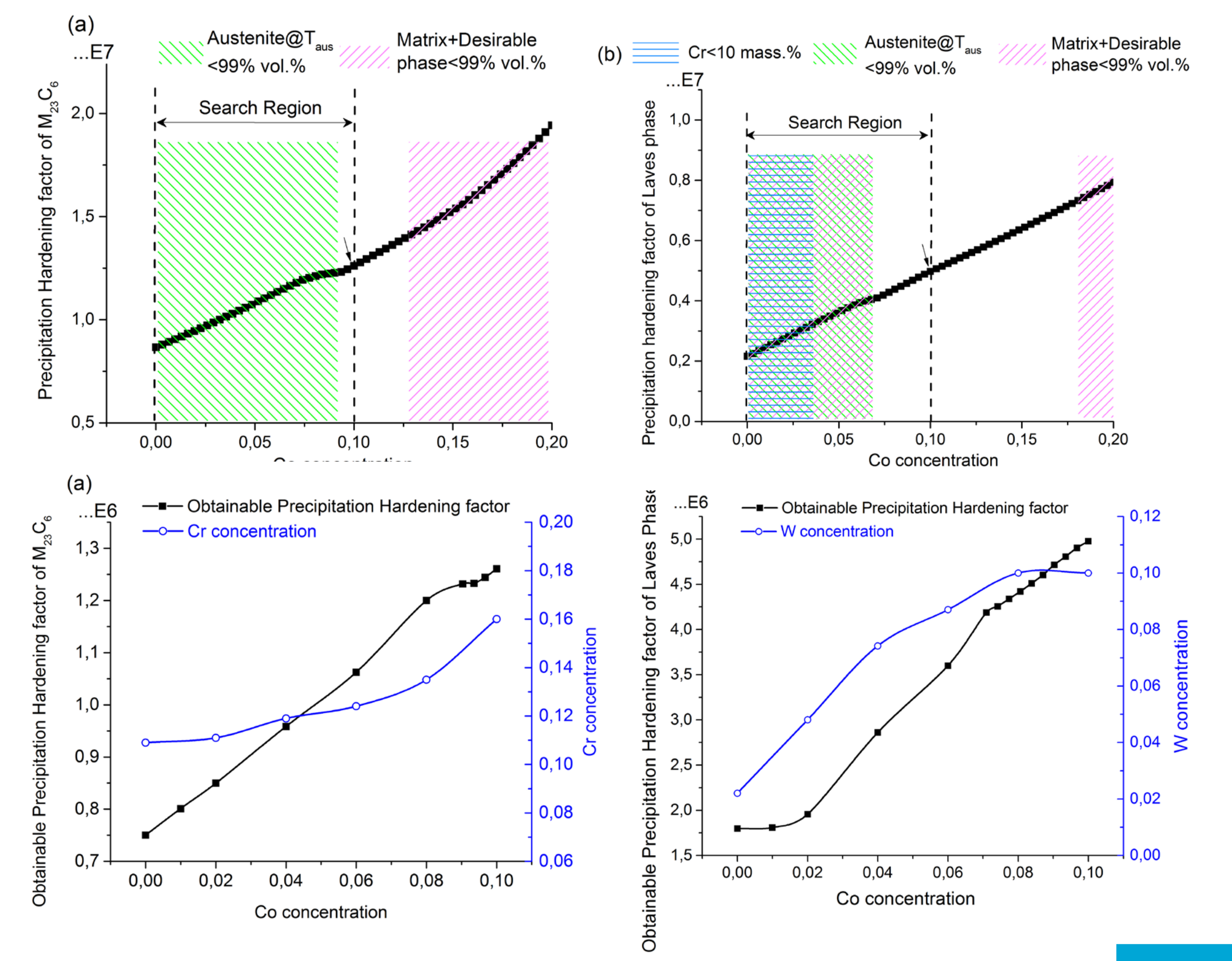
	C	*Cr*	*Ni*	*W*	*Co*	*Nb*	*N*	*V*	*Mo*	*Ti*	*Al*	*Taus/°C*
LavesW	0.001	10.84	3.23	10.00	**10.00**	0.32	0.03	0.001	0.00	0.11	0.001	1239
$M_{23}C_6W$	0.15	16.00	0.01	1.61	**10.00**	0.001	0.006	1.00	0.00	0.01	0.001	1069

Results

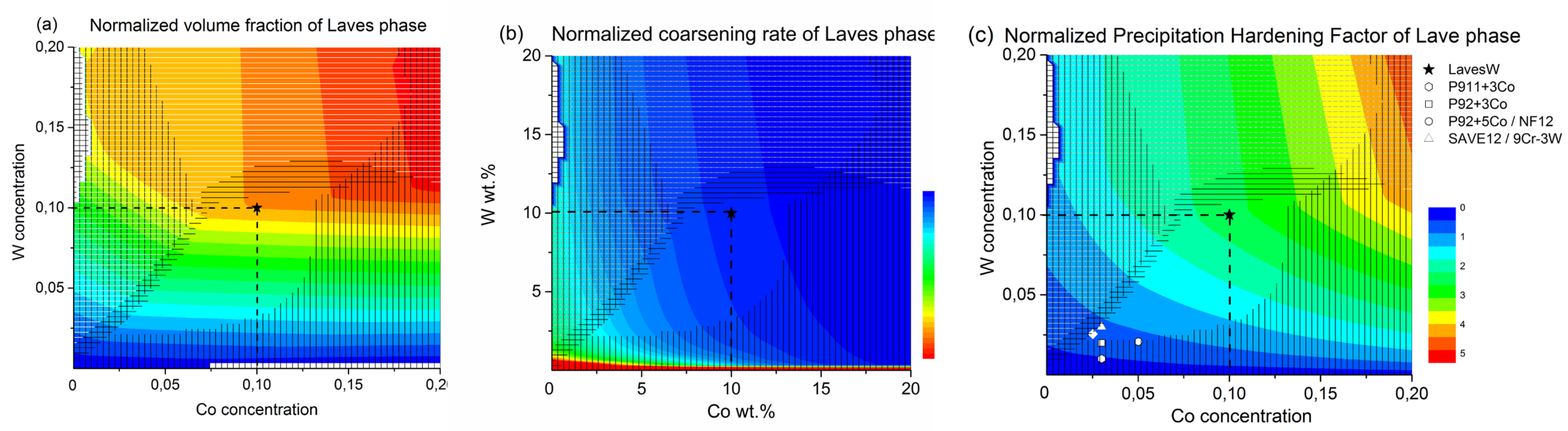
Compared with existing grades



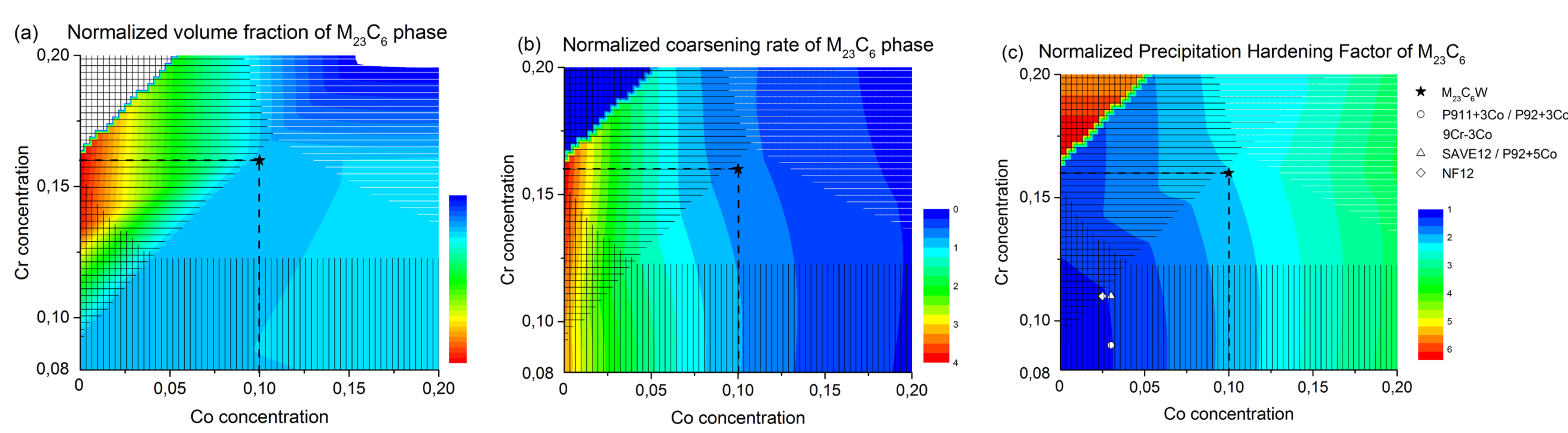
The effect of Co element



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 M23C6W alloy, Co plays an irreplaceable role.**

References:[1]Hao Yu, Wei Xu, Sybrand van der Zwaag. Steel Research International, accepted.
[2]Qi Lu, Wei Xu, Sybrand van der Zwaag. Metallurgical and Materials Transactions A. 2014;45:6067-74

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