

Design of highly formable and ultra-strong alloys through Plasticity Induced transformations in Titanium alloys (PiTTi)



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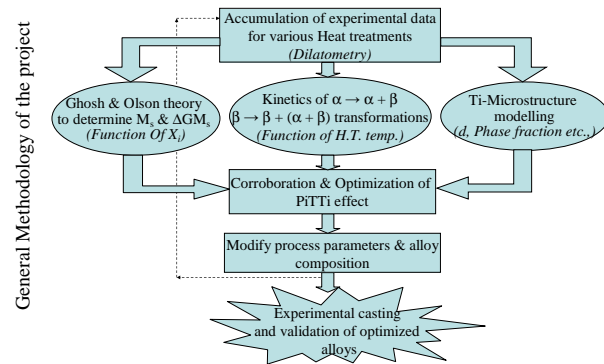


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Fundamentals of Advanced Materials

Objective and strategy

The present work is aimed at designing Ti alloys with optimum strength and ductility: the much demanded properties for their structural applications. It is intended to achieve this by utilizing the concept of Transformation Induced Plasticity (TRIP) from ferrous technology, referred here as plasticity induced transformation in Titanium alloys (PiTTi). It is essential to understand the effect of various factors including microstructure, composition and deformation state, which in turn depend on the alloy heat treatment on PiTTi. A thermo-kinetic model to compute the phase transformation kinetics, and a model for M_s temperature prediction has been developed. The models incorporate the various factors for ternary and higher order systems to tailor their PiTTi effect. Thermodynamic equilibrium is ensured by coupling the models with a thermochemical database (Thermo-calc).



Comparison of Kinetics model and Experiments

Thermo-kinetic model: The effect of heat treatment variables on PiTTi is considered. The model computes the phase kinetics as a function of heat treatment parameters and alloy composition.

Model parameters (Fig.1): A , a cross-section of the transformation front; K_{TOT} , total length of the transformation volume; R_{AB} , interface position; C_o^α and C_o^β , concentrations at the far field of α and β phases, respectively; $C_o^{\alpha\beta}$ and $C_o^{\beta\alpha}$, concentrations of α and β phases in equilibrium with each other, respectively.

Input: Heat treatment temperature, heating rate and start temperature.

Output: Volume fraction of different phases and phase concentrations with time.

Assumption: Local equilibrium at the interface.

Application: Effect of the heating rate, start temperature and annealing temperature on the heat treatment kinetics of Ti-10V-2Fe-3Al (wt.%) alloy is represented by the change of V concentration in β (Fig. 2).

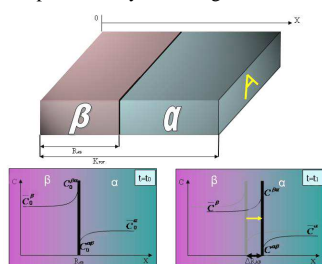


Figure 1. Geometry of the model

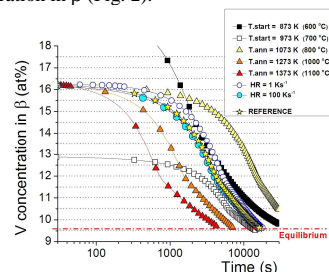


Figure 2. Heat treatment kinetics by V concentration changes; reference - heating from 650°C to 900°C

Experiments: Dilatometry has been performed to experimentally study the heat treatment effects on Ti-10V-2Fe-3Al alloy. The agreement between the trends predicted by the simulation and the experiments are reasonably good. For instance, the dilatometry curves suggest that the alloy does not reach equilibrium (Fig. 3) even after 120 min (7200s) of soaking. This agrees well with the simulated heat treatment (900°C), where the equilibrium V concentration is reached only after $\sim 10^5$ s. The microstructure with different phases also proves the non-equilibrium state of the alloy (Fig. 4).

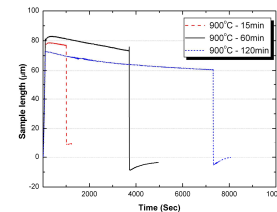


Figure 3. Dilatometry curves at 900 °C

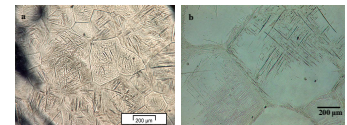


Figure 4. Heat treatment at 900 °C for a) 15 mins. b) 120 mins.

Model for M_s temperature prediction

Local concentration changes in the microstructure result in the formation of different phases including martensite. Martensite formation studies is important to tailor the PiTTi. The M_s temperature of multi-component alloys is predicted using the **Ghosh-Olson approach** [*Acta. Met.*, Vol. 42, pp. 3361, 1994].

Model Concept: The critical condition for martensite nucleation is attained by a balance between the negative fault energy and the interfacial frictional work, given as

$$-\Delta G_{crit} = K_1 + W_\mu (K_\mu^i, X_i), \quad W_\mu = \sqrt{\sum (K_\mu^i X_i)^2}$$

Where K_1 is a constant that includes the fault energies, K_μ^i is the athermal strength of different solutes i , W_μ is the athermal (only composition dependent) interfacial frictional work

Input: $-\Delta G$ at M_s temperature vs. Composition for various binary systems.

Output: Energy values and athermal strength of different solutes i .

Assumptions: Weak composition and temperature dependence of Shear modulus.

Application: The present investigation deals with Ti-10V-2Fe-3Al (wt.%) alloy. Assuming a linear relation of $-\Delta G$ at M_s with composition, K_1 and K_μ^i 's for V, Fe, Al in Ti is obtained (Fig. 5) The overall $-\Delta G_{crit}$ (calculated using Thermo-calc) for the considered alloy is 2285.7 J/mol and the corresponding M_s temperature is 342°C (using Thermo-calc).

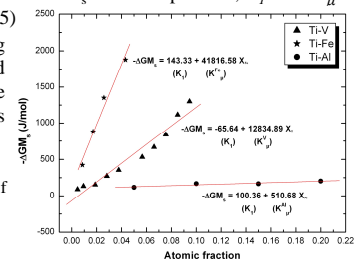


Figure 5. Composition dependence of the $-\Delta G$ at M_s in Ti-base alloys

Future work

Extending the thermo-kinetic model to higher order systems by considering various factors like impingement and the morphology of phases.

Improving M_s temperature model by accounting shear modulus components and devising the exact composition dependence trend.

Experimental validation of the computed optimum alloy for PiTTi.

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