Optimization of RAFM steels for high temperature applications by increasing Ta/V content

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Methods

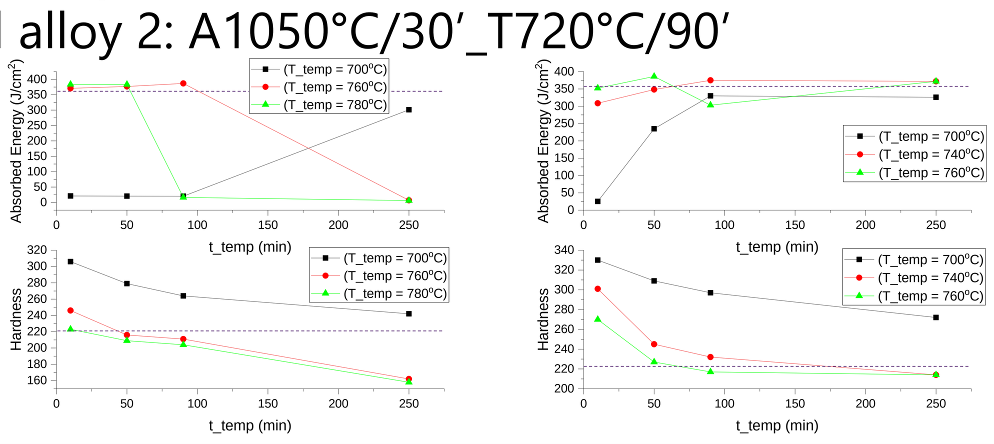
A search algorithm has been developed to select a combination of compositions and heat treatments that leads to improved creep resistance with respect to the reference material EU97-2. Two model alloys were designed with the chemical compositions shown in Table 1. Low carbon content to reduce irradiation embrittlement and high carbo/nitride formers content was achieved to insure high fraction of finely dispersed MX precipitates.

wt %	C	Mn	Si	Cr	W	N	V	Ta
Model alloy 1 (M471)	0.0437	0.4090	0.049	9.0135	0.4670	0.0244	0.3610	0.488
Model alloy 2 (M472)	0.0457	0.4057	0.030	8.611	0.8530	0.0620	0.2263	0.379
wt %	**C**	**Mn**	**B**	**Cr**	**W**	**N**	**V**	**Ta**
EU97-2 [1]	0.11	0.53	0.00023	8.8	1.1	0.041	0.2	0.12

Table 1: Chemical Composition of Model Alloys.

Screening of heat treatments in high throughput simulator was performed to choose thermal treatment which gives the best combination of mechanical properties i.e. hardness and absorbed energy. Two heat treatments were chosen for upscaling:

- model alloy 1: A1050°C/30’_T740°C/50’
- model alloy 2: A1050°C/30’_T720°C/90’



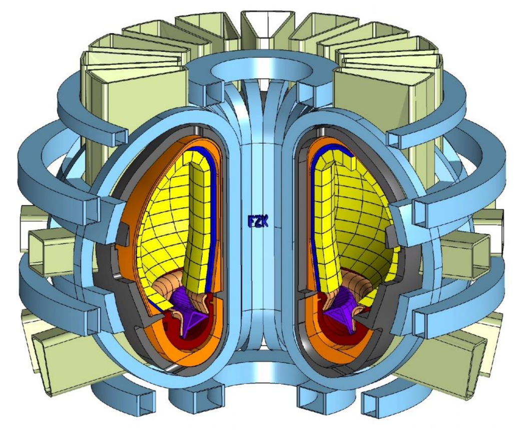
Introduction

Reduced activation ferritic/martensitic steels (RAFM) is the best candidate to be used as a structural material in breeding blanket for future fusion reactors. Depending on blanket coolant choices, RAFM steels should either have high strength at temperatures above 550°C (He cooled reactor) or superior radiation-embrittlement properties at lower temperatures (~290–320 °C), for construction of water-cooled blankets.

Current operating temperature window: 350ºC – 550ºC

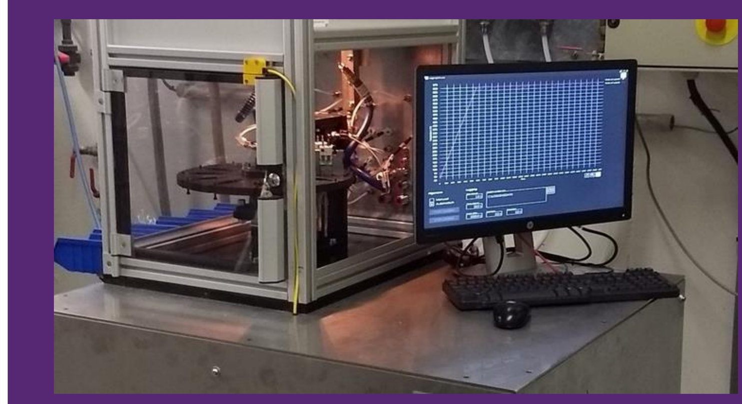
Water-cooled (T<350ºC)
- Low temperature RAFM
  - Irradiation-induced embrittlement

He-cooled (T>550ºC)
- High temperature RAFM
  - Creep



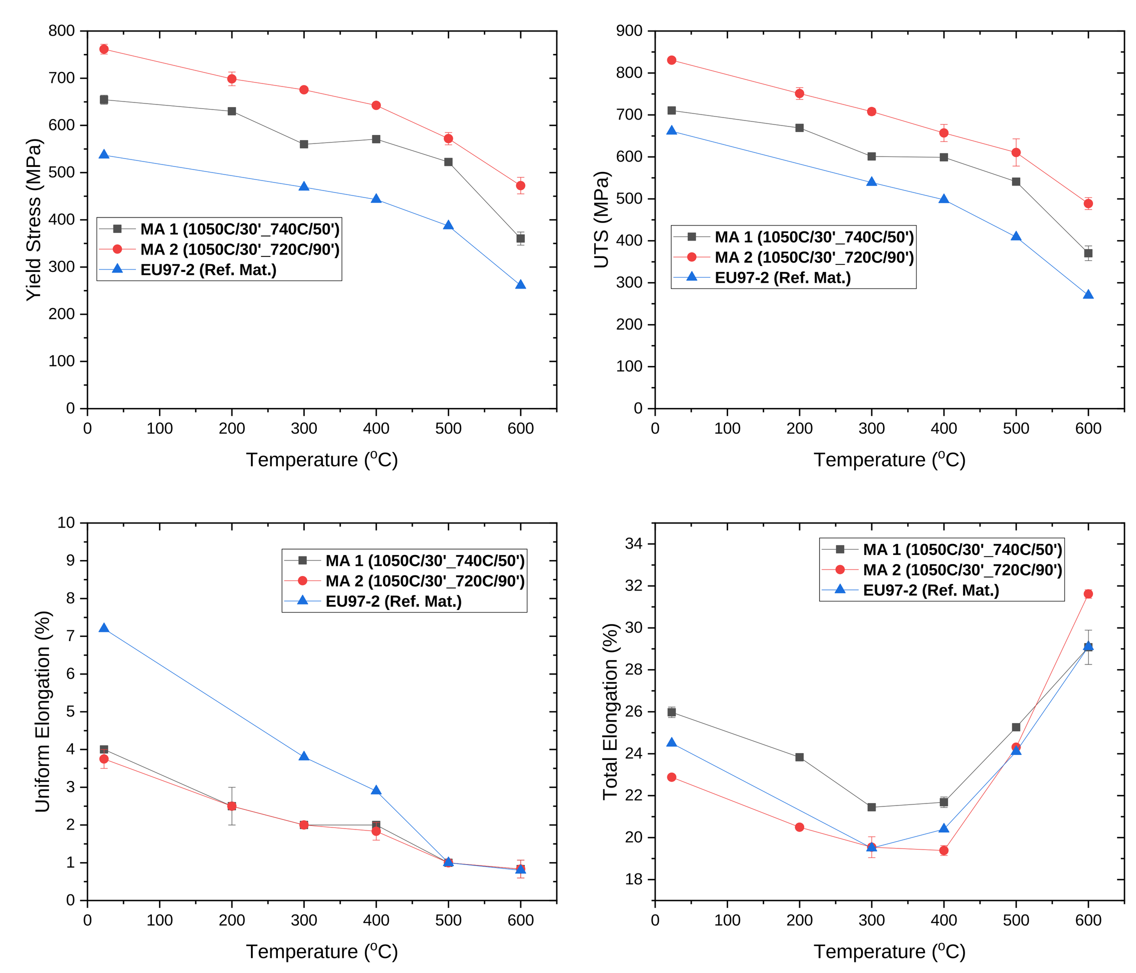
Objectives

The objective of this work is to produce RAFM steels for high temperature applications with improved creep resistance with respect to EU97-2 while demonstrating the adequate low temperature performance of the material.

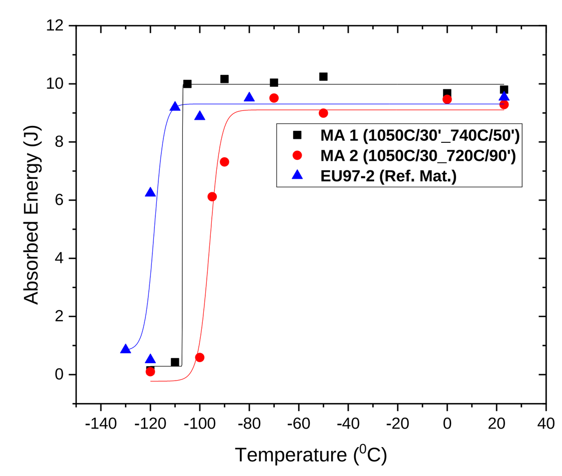


Results

Both model alloys have higher yield and ultimate tensile strength (UTS) in comparison with EU97-2. Both model alloys exhibit a lower uniform elongation at room temperature in comparison with EU97-2. The total elongation of MA1 is greater than the total elongation of EU97-2 and MA 2.

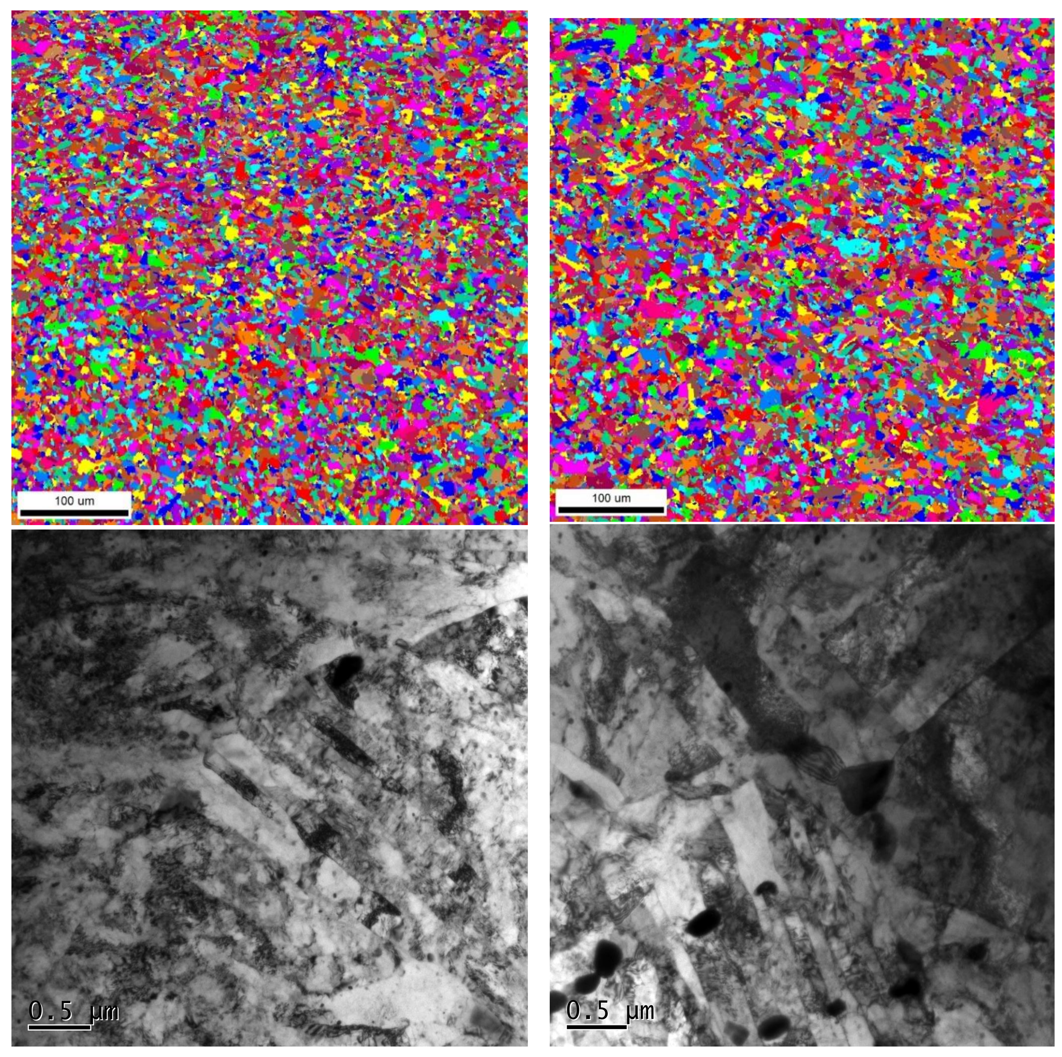


Model alloys have fully martensitic structure with fine block and lath sizes. Mechanical performance was evaluated based on tensile, hardness and Charpy tests. Tensile properties of model alloys are superior to EU97-2 whereas impact properties are comparable to EU97-2.



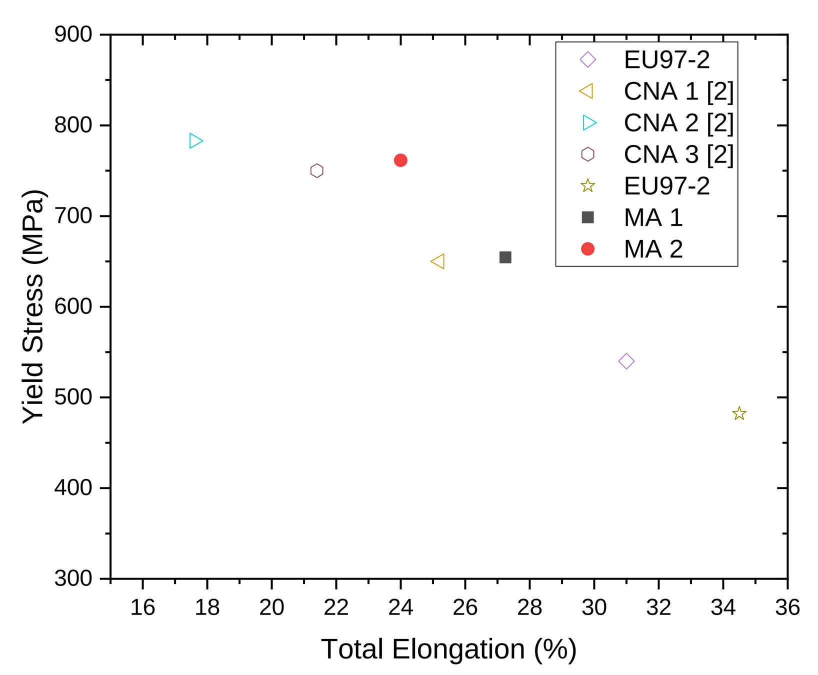
DBTT of MA 1 = -107 °C and USE = 10 J and DBTT of MA 2 is – 96 °C and USE = 9.2 J
DBTT of EU97-2 = -110 °C and USE = 9.2 J

Microstructure of model alloys



Discussion

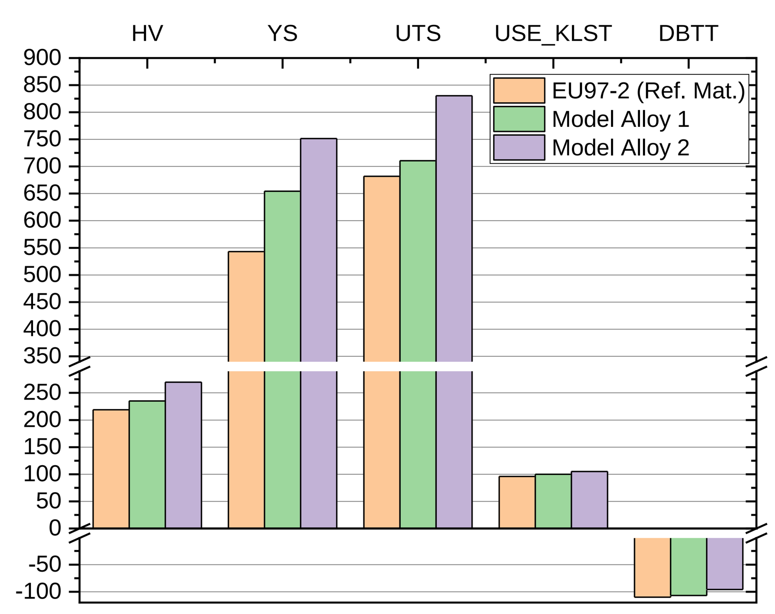
Experimental results of the new alloys developed in this work demonstrate the mechanical behavior that correlates well with the observed microstructure. Model alloys have similar yield stress compared to CNA grades [2], whereas total elongation of model alloys is greater. Two types of EU97-2 steel have lowest yield stress while having greatest total elongation. Overall, one can see that the total elongation decreases with an increase of the yield strength.



Total elongation vs. yield strength for model alloys and other types of RAFM steels. Open symbols show the data taken from the literature.

Conclusion

The experimental results confirm that the search algorithm used to manipulate the thermodynamic database enables compositions and heat treatments that resulted in new alloys with improved tensile strength and comparable to EU97-2 impact properties. The obtained experimental results demonstrate the feasibility of using thermodynamic models in optimization of RAFM steels and validate the predictions made by thermodynamic modelling given well defined boundary conditions and search criteria.



Comparison of mechanical properties of model alloys after HT 2 with EU97-2 [1]. The values of USE are magnified by a factor of 10 to enhance readability of the data. Upper shelf energy of KLST samples was multiplied by a factor of 10.

[1] Materna-Morris *et al.*, "Structural material EUROFER97-2, Characterization of Rod and Plate Material: Structural, Tensile, Charpy and Creep Properties," Institut für Materialforschung, Forschungszentrum Karlsruhe, 2007
[2] Tan, L., L.L. Snead, and Y. Katoh, Development of new generation reduced activation ferritic-martensitic steels for advanced fusion reactors. Journal of Nuclear Materials, 2016. 478: p. 42-49