Production and characterization of 9Cr HT RAFM steels

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Methods

A search algorithm has been developed to select a combination of composition 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.

Lab-cast EUROFER (M474)
Modelled HT: A880°C/30'_T750°C/120'

Model Alloy 1 (M471)
- M471_1 Modelled HT: A1050°C/30' T780°C/120'
- M471_2 Standard HT: A980°C/30' T760°C/90'

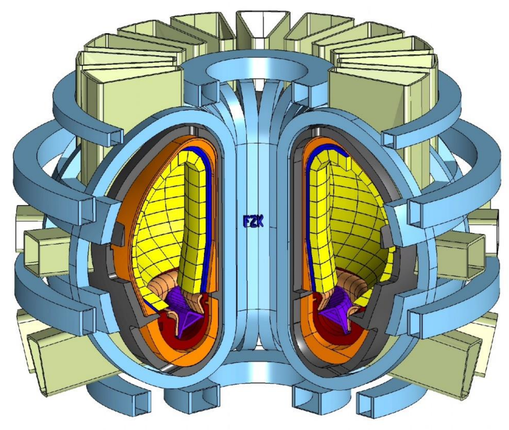
Model Alloy 2 (M472)
- M472_1 Modelled HT: A1050°C/30' T650°C/120'
- M472_2 Standard HT: A980°C/30' T760°C/90'

In search of new alloys:
- complete austenitization at T_{aust} (no ferrite)
- max. dissolution of MX precipitates at T_{aust}
- max. volume fraction of MX at T_{temp}
- no $M_{23}C_6$ at T_{temp}

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

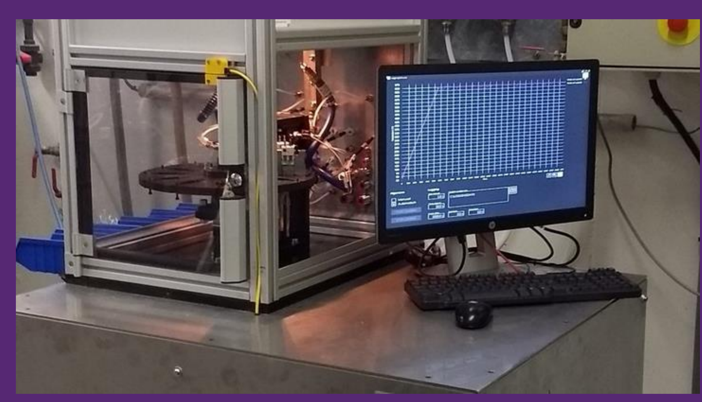


Water-cooled (T<350ºC)
- Low temperature RAFM
  - Irradiation-induced embrittlement

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

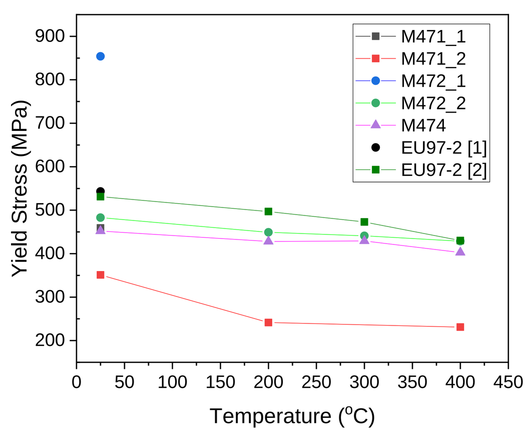
Objectives

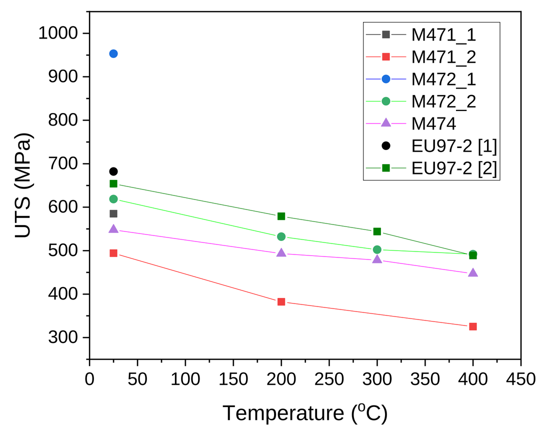
The objective of this work is to produce RAFM steels for high temperature applications with improved creep resistance with respect to EU97-2 while demonstrating the adequate low temperature performance of the material.



Results

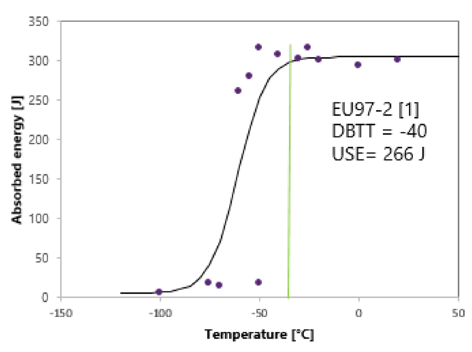
Model alloy 1 (M471_1) has YS comparable to EU97-2 but very low YS after standard HT (M471_2). Model alloy 2 (M472_1) has the highest YS and also comparable YS after standard HT (M472_2).

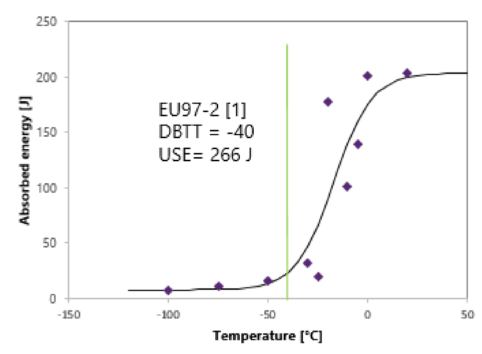




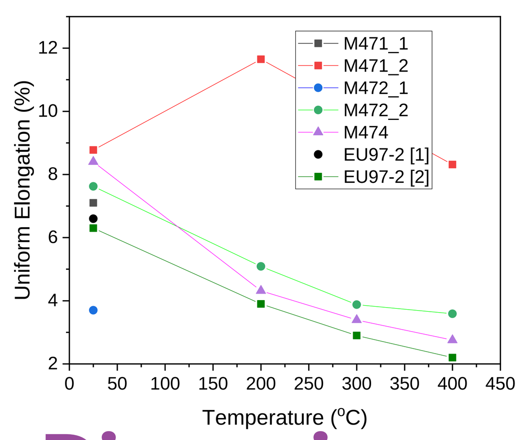
Model alloys have fully martensitic structure (except M471 standard HT). Block and lath sizes are comparable to lab-cast EUROFER. Mechanical performance was evaluated based on tensile, hardness and Charpy tests. Tensile properties of model alloys are comparable to EU97-2 whereas impact properties are superior.

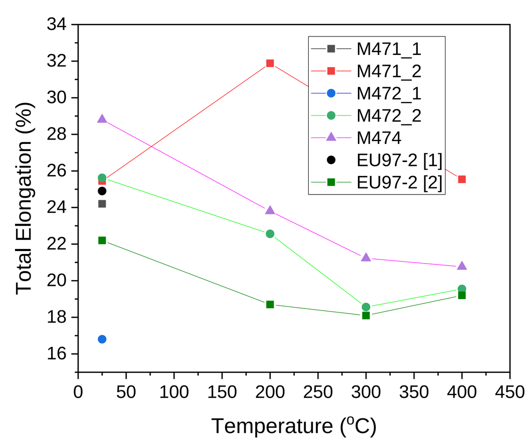
Model Alloy 1 (M471_1) has lower DBTT as well as higher USE than EU97-2 [1].

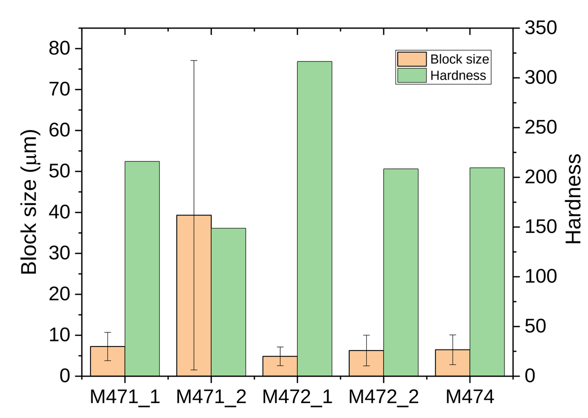


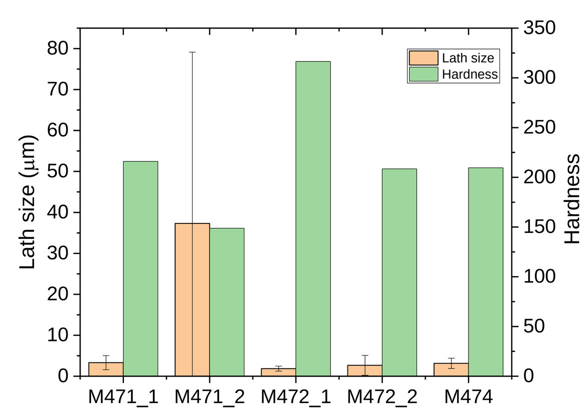


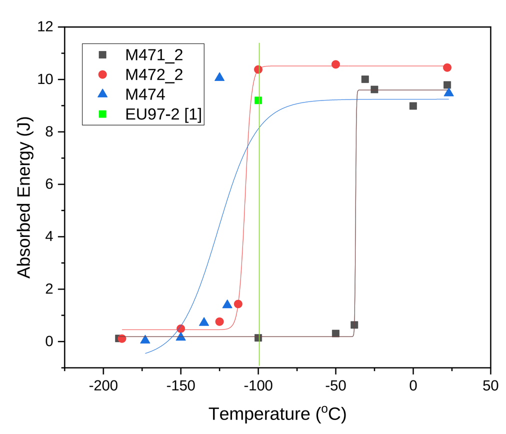
DBTT of model alloy 2 after standard HT (M472_2) = -108.5 ± 1.7 °C and USE = 10.5 ± 0.2 J
DBTT of EU97-2 = -100 °C and USE = 9.2 J

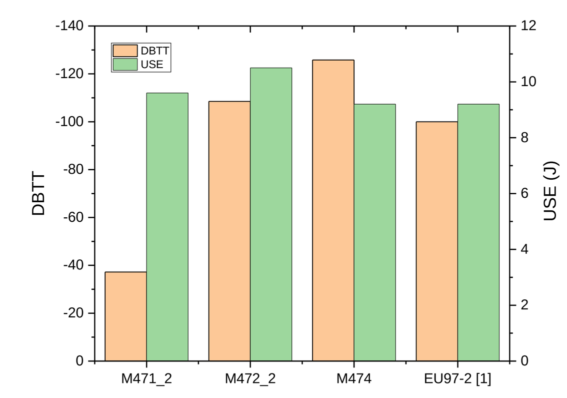








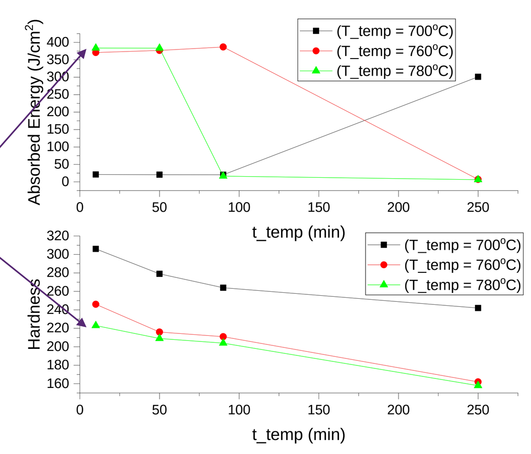




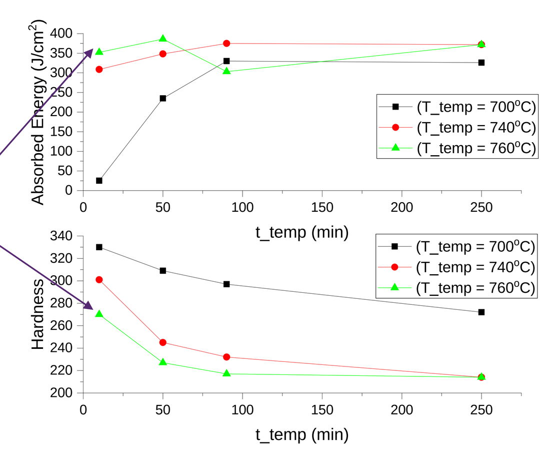
Discussion

Further tuning of heat treatment in high throughput simulator showed that the highest T_{temp} combined with the shortest t_{temp} gave the best combination of mechnanical properties i.e. hardness and absorbed energy.

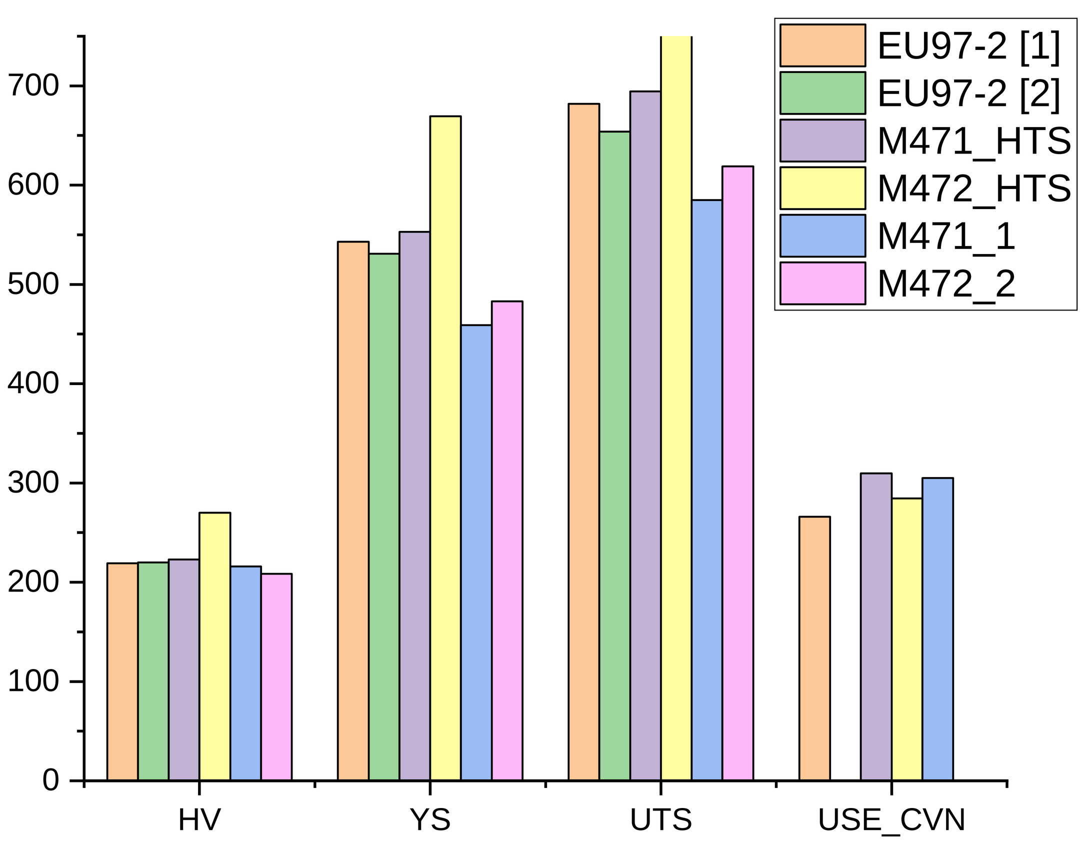
A1050°C/30'_T780°C/10'
HV = 223
SAE at - 60 °C = 383.6 J/cm²



A1050°C/15'_T760°C/10'
HV = 270
SAE at -20°C = 352.4 J/cm²



Two heat treatments were chosen for upscaling:
- model alloy 1 (M471): A1050°C/30'_T780°C/10'
- model alloy 2 (M472): A1050°C/15'_T760°C/10'



Conclusion

- Model alloy 1 (M471_1) and model alloy 2 after standard HT (M472_2) showed slightly lower YS but superior impact properties compared to EU97-2.
- Low yield stress of model alloy 1 after standard HT (M471_2) could be explained by heterogeneous grain growth due to undissolved TaC particles [3]
- Very high yield stress of model alloy 2 (M472_1) could be due to lowest T_{temp} (650°C)
- Both hardness and absorbed energy of upscaled grades lie above EU97-2 [1].
- Ongoing tensile/charpy tests to confirm the improvement made

[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] Material Property Handbook EUROFER97
[3] Xia Zhi-Xin *et al.*, "Effect of TaC Particles Dissolution on Grain Coarsing in Reduced Activation Steels", Journal of Iron and Steel Research, 2011