Superferritic-type alloy for fabrication of heat exchangers by Additive Manufacturing

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Alkaline environment, present in absorption machines based on ammonia-water cycle, can cause severe corrosion in particular in heat exchangers. In these machines, the heat, required by the thermodynamic cycle, can be supplied by renewable energy sources, for example using solar collectors. Heat exchangers and rich solution pumps are critical components due to severe corrosion. The materials are in fact exposed to diverse conditions, as ammonia-water solutions with different concentrations are present in the machine. An alloy design approach, based also on the use of thermodynamic modelling software, allowed defining the chemical composition of a new ferritic alloy. The Ni-free alloy has been produced by Vacuum Induction Melting (VIM) and successively gas atomized in order to produce a powder suitable for powder bed fusion additive manufacturing technologies. Microstructural characterization by Scanning Electron Microscopy (SEM) and X-Ray diffraction (XRD) revealed the formation of ferritic phase in as melted and gas atomized materials. Tensile and corrosion tests showed suitable mechanical and corrosion resistance properties for the realization of heat exchangers for alkaline environments. Moreover, printing parameters for laser powder bed fusion methods have been developed achieving a density of about 99.9%.

- Severely corrosive alkaline environment due to ammonia could stress materials till component failure during machine operation;
- Copper and Nickel are heavily affected by the presence of ammonia: formation of complexes;
- A new ferritic alloy has been designed with the aim of realizing by 3D printing the heat exchangers for absorption machines;

- Ferritic steels have generally higher thermal conductivity respect to austenitic stainless steels generally used for this type of heat exchangers;
- lower linear expansion coefficient respect to austenitic steels (reduction of thermo-mechanical fatigue);
- Lower alloy costs due to nickel, molybdenum and chromium content reduction

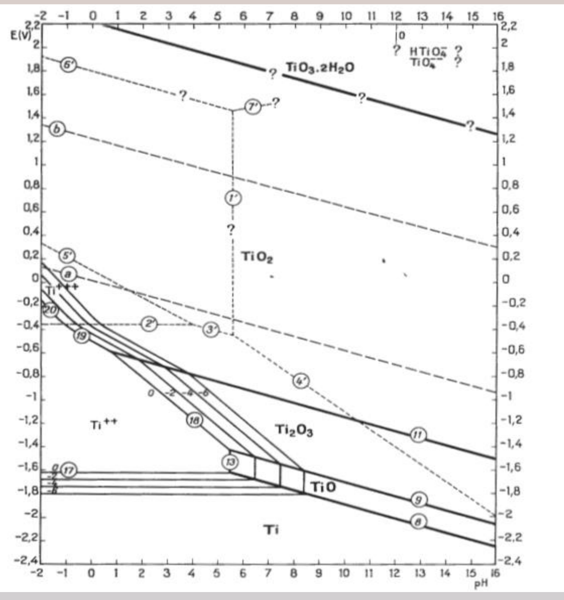
Theoretical corrosion studies

$NH_3+H_2O \Leftrightarrow NH_4^++OH^-$

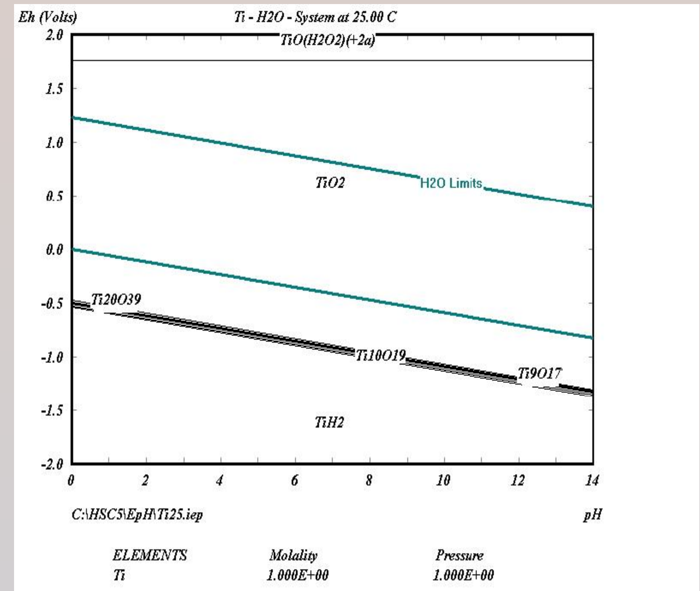
Dissociation of NH_3 in water

Pourbaix diagrams, tension-pH, allow to describe the theoretical behaviour of chemical elements in aqueous solutions at different temperature and pressure.

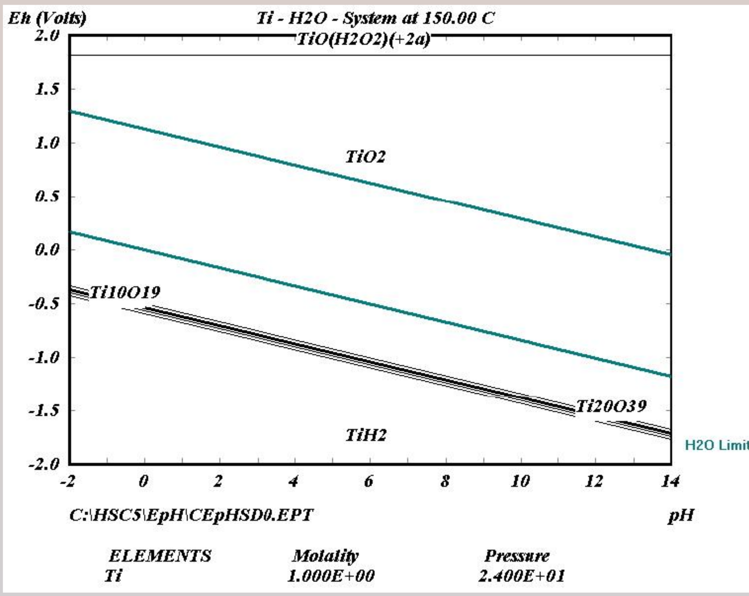
The code HSC_5 developed in HSC-Chemistry software has been used to calculate Pourbaix diagrams



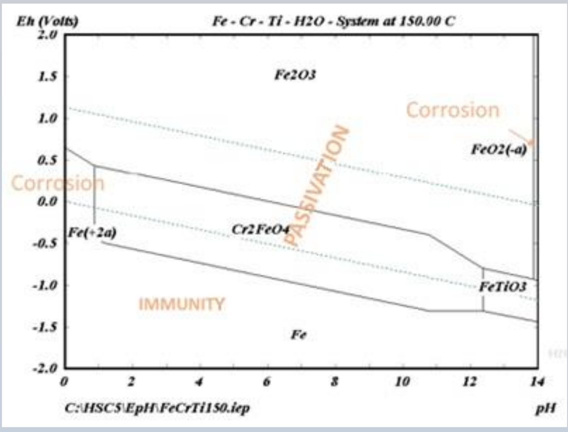
Theoretical Pourbaix diagram of Ti in aqueous solution at 25°C and atmospheric pressure



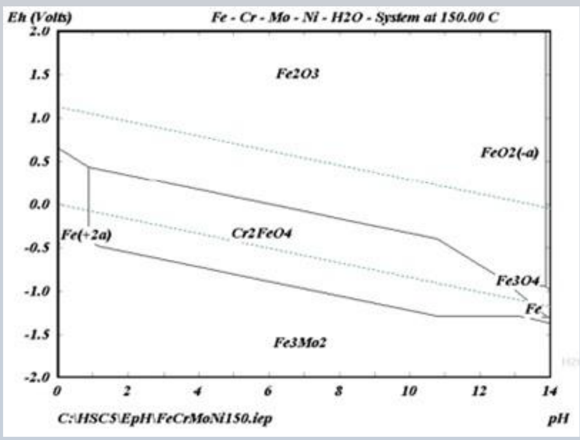
Calculated Pourbaix diagram of Ti in aqueous solution at 25°C and atmospheric pressure



Calculated Pourbaix diagram of Ti in aqueous solution at 150°C and 24 bar



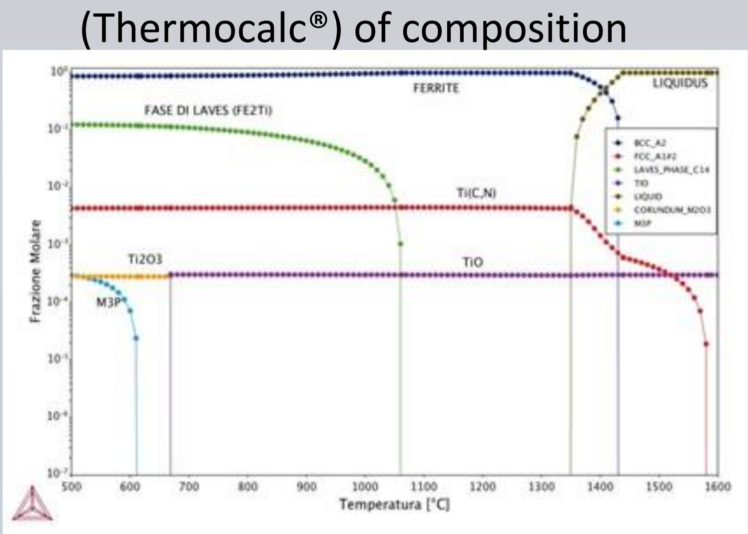
Calculated Pourbaix diagram of Fe-Cr-Ti in aqueous solution at 25°C and atmospheric pressure



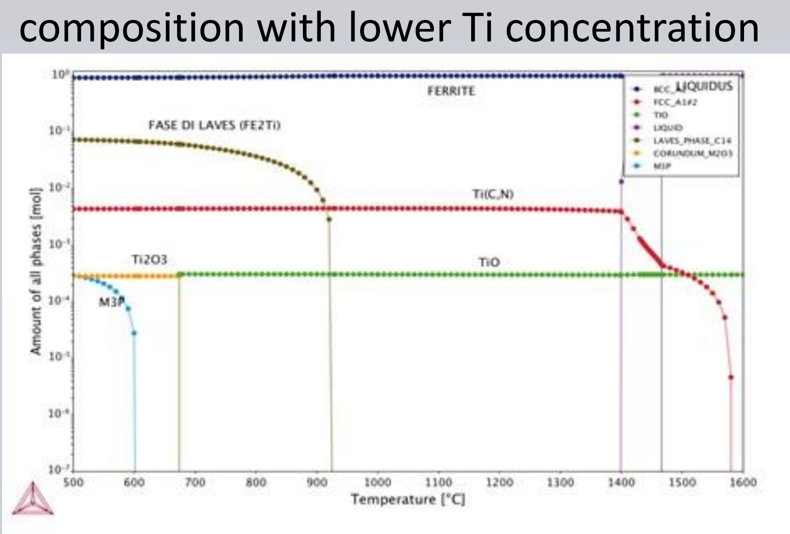
Calculated Pourbaix diagram of Fe-Cr-Mo-Ni in aqueous solution at 25°C and atmospheric pressure (AISI 316)

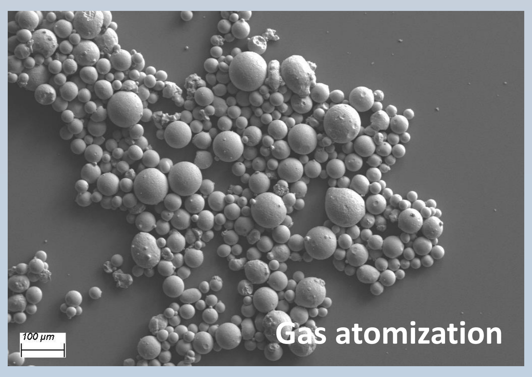
Thermodynamical studies and alloy specifications

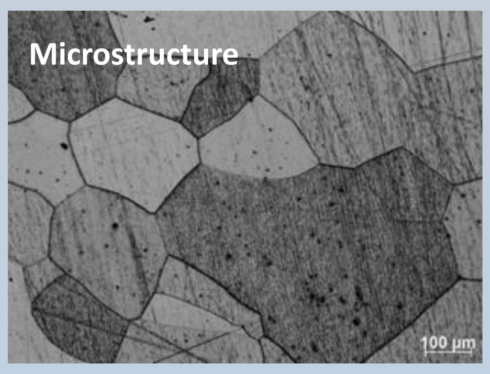
Stepped Calculation Graph (Thermocalc®) of composition

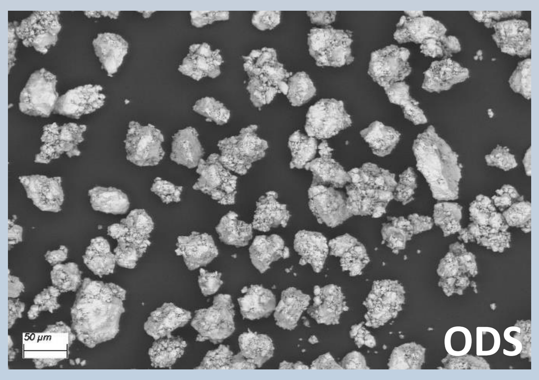


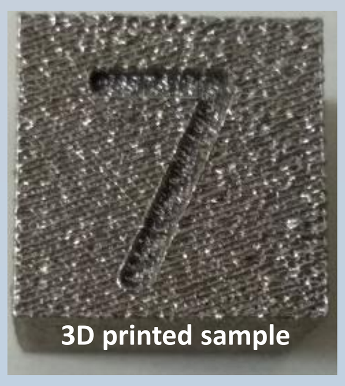
Stepped Calculation Graph (Thermocalc®) of composition with lower Ti concentration

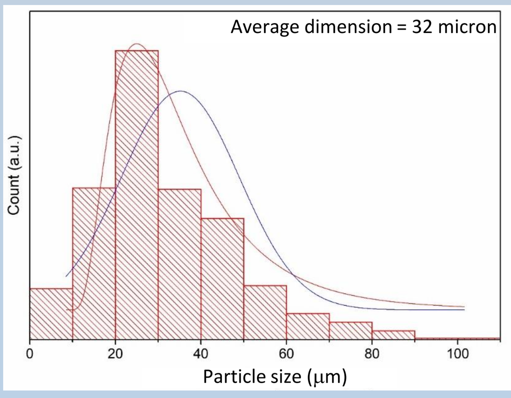


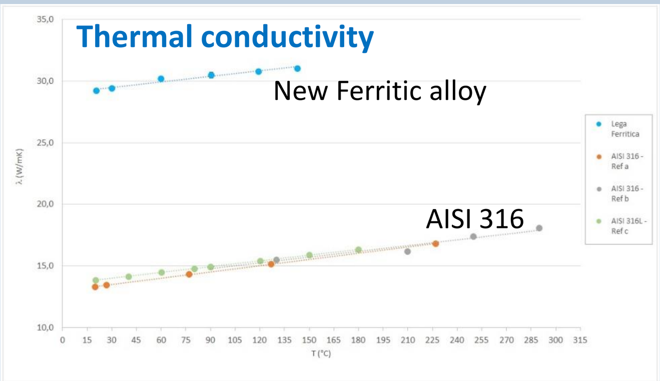












Mechanical properties

Campioni	Sy Rp 0,2%		Su Rm		El. A	R.A. Z
	Ksi	N/mm²	Ksi	N/mm²	%	%
T1	48,4	333,7	60,0	413,9	8,3	21,1
T2	44,8	309,0	62,0	427,5	-	-
T3	45,6	314,1	57,7	397,6	16,4	-
T1-150°	46,3	319,0	56,0	385,9	30,7	-
T2-150°	49,2	339,1	59,6	410,6	-	-
T3-150°	42,8	295,1	54,7	377,4	26,0	-

- A bar of alloy has been produced by Vacuum Induction Melting;
- The bar has been gas atomized by Electrode induction melting Inert Gas Atomization (EIGA) to produce spherical powder particles;
- The ferritic steel presents:
  - an higher thermal conductivity respect to AISI 316;
  - linear expansion coefficient smaller respect to AISI 316;
  - Good corrosion resistence in water/ammonia solution at 25°C and 150°C;
- ODS has been obtained by high energy ball milling (0.3% nano-Y_2O_3);
- Printing parameters have been developed for a Laser Powder Bed Fusion process (Direct Metal Laser Melting, DMLS) and some samples have been realized for microstructural characterization.

Conclusions: a new ferritic alloy has been designed and produced by gas atomization for the realization of heat exchangers by Additive manufacturing. The alloy present an higher thermal conductivity and lower linear expansion coefficient respect to AISI 316, good corrosion resistence in ammonia environment at 25 °C and 150°C. Printing parameters for DMLS process have been developed.

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Ref.: G. Corallo, A. Franchi, Report RdS/2011/246; D. Mirabile Gattia, L. Pilloni, G. Corallo, Report RdS/PTR2021/227