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Design of a superferritic-type alloy for AM fabrication of heat exchangers in severe liquid alkaline environment

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Abstract: Materials used for heat exchangers in absorption machines, based on ammonia-water cycle, are heavily affected by severe corrosion in alkaline environment. In these machines the heat exchangers and rich solution pump are essential parts. In ENEA, in the past, a 18 kW (cooling) machine has been realized based on ammonia-water cycle which demonstrated interesting potentialities when heat, required by the thermodynamic cycle, is supplied by renewable energy sources, as for example using solar collectors [1]. One of main critical issues in these machines is due to the severe corrosion the materials undergo in contact with solutions with different concentrations of ammonia. In this framework, preliminary ENEA's results are reported about the design of a new ODS alloy which could be used for the realization of heat exchangers. The work considers on one side the definition of a chemical composition of the alloy, based on alloy design approach, and on the other side the realization of this alloy by gas atomization for its use in metal 3D printers, based on powder bed or direct deposition processes. In order to strengthen the alloy from a mechanical point of view the attempt of dispersing suitable dispersoids (as nano-Y_2O_3) will be achieved by mechanical milling. The activity is funded by the Program Agreement with the Italian Ministry of Economic Development "Advanced materials for energy", PTR 2019-2021.

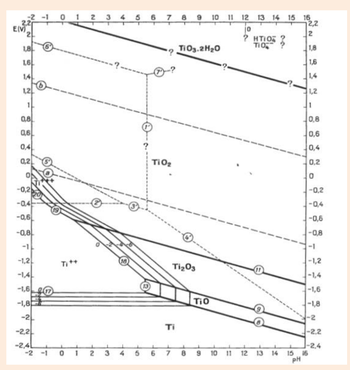
- Severely corrosive alkaline environment due to ammonia could stress materials till component failure during machine operation;
- Copper and Nickel are heavily affected by the presence of ammonia;
- A new ferritic alloy has been designed with the aim of realizing by 3D printing the heat exchangers for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

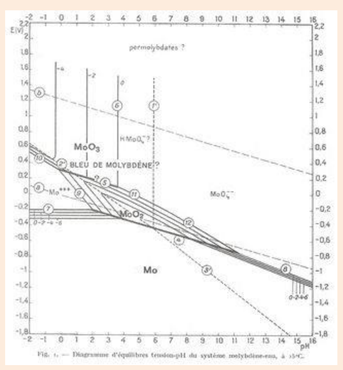
Pourbaix diagrams, tension-pH, allow to describe the theoretical behaviour of chemical elements in aqueous solutions at different temperature and pressure.

The code HSC_5 developed in HSC-Chemistry software has been used to calculate Pourbaix diagrams [3]

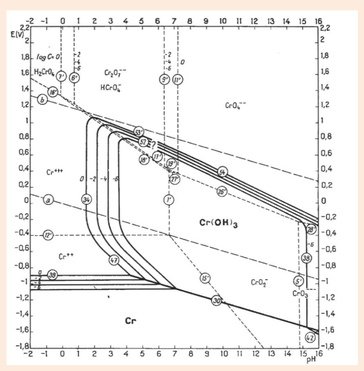
$NH_3+H_2O \Leftrightarrow NH_4^+ + OH^-$
Dissociation of NH_3 in water



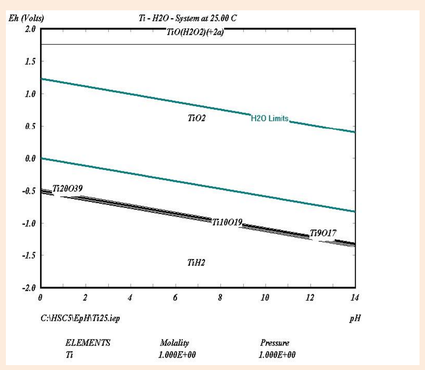
Theoretical Pourbaix diagram of Ti in aqueous solution at 25°C and atmospheric pressure [2]



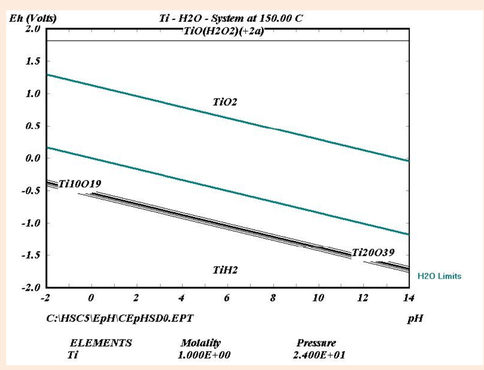
Theoretical Pourbaix diagram of Mo in aqueous solution at 25°C and atmospheric pressure [2]



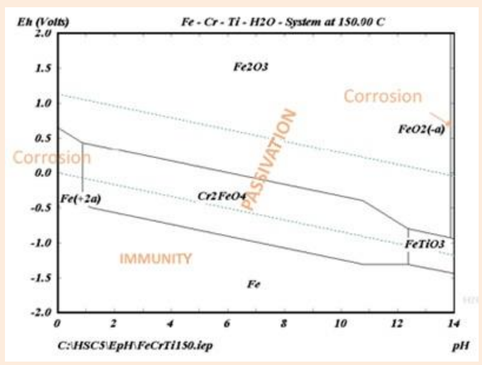
Theoretical Pourbaix diagram of Cr in aqueous solution at 25°C and atmospheric pressure [2]



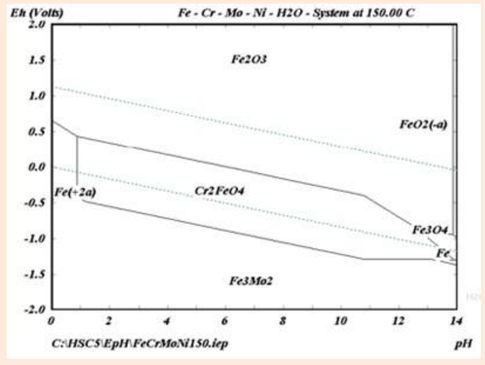
Calculated Pourbaix diagram of Ti in aqueous solution at 25°C and atmospheric pressure



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

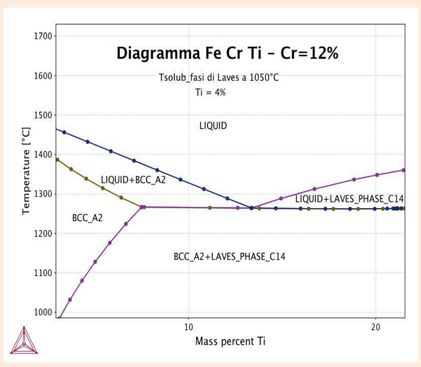


Calculated Pourbaix diagram of Fe-Cr-Ti in aqueous solution at 25°C and atmospheric pressure

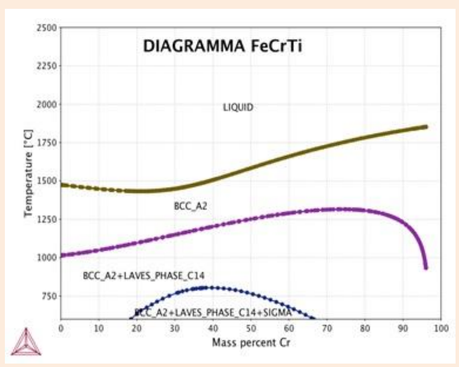


Calculated Pourbaix diagram of Fe-Cr-Mo-Ni in aqueous solution at 25°C and atmospheric pressure (AISI 316)

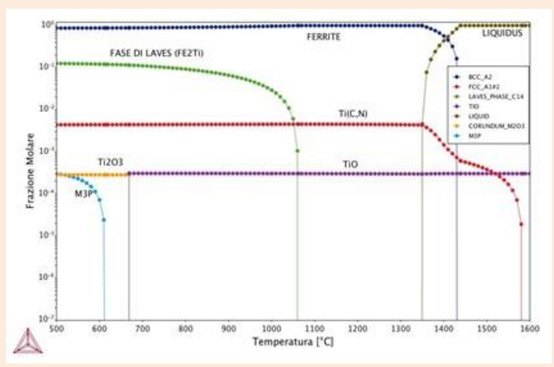
Thermodynamical studies and alloy specifications



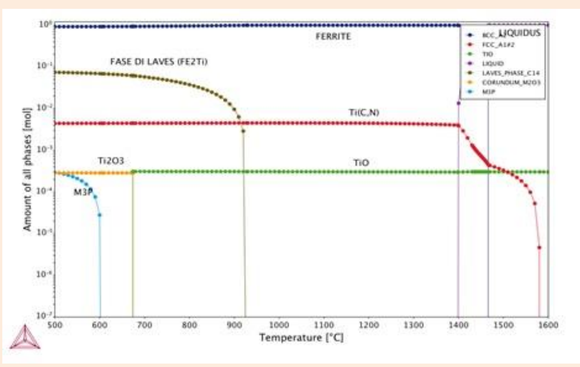
Pseudo-binary diagram of Fe 12Cr xTi system (ThermoCalc®)



Pseudo-binary diagram of Fe Ti xCr system (ThermoCalc®)



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



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

Conclusions

The work reports the alloy design of a superferritic-type stainless steel which will be the base alloy for the **ODS** fabrication, to be used in 3D metal printing processes. **The powders obtained by gas atomization have just been purchased**. The next step will be to disperse nanometric oxides within the powders, using mechanical alloying process. The nanometric oxide dispersion will increase the material's mechanical strength contributing to lower the thickness of the walls of the channels in the heat exchanger. This will increase the heat exchange performance of the whole system [4].

[1] G. Corallo, A. Franchi, Realizzazione di un prototipo reversibile di macchina ad assorbimento da 18 kW con alimentazione ad acqua calda da adibire al solar cooling and heating e prove sperimentali preliminari. Report RdS/2011/246
[2] M.Pourbaix "Atlas of Electrochemical equilibria in aqueous solutions" NACE Ed. (1977)
[3] HSC-Chemistry (Versione 5) by Chemistry Software, Suite #829, 1321 Upland Drive, Houston, TX 77043, USA
[4] Daniele Mirabile Gattia, Luciano Pilloni, Giuseppe Corallo, Sviluppo di lega metallica per additive manufacturing per utilizzo in applicazioni per scambio termico, Technical Report RDE PTR 2019-2021