Development of a ferritic alloy for AM of heat exchangers for corrosive environments

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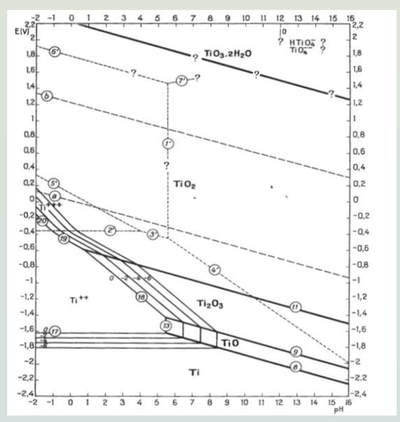
Absorption machines, coupled with renewable energy sources, can be used for cooling applications. If the working fluids is ammonia-water solution, the components in these machines, in particular heat exchangers, can be affected by the highly corrosive alkaline environment. Generally, heat exchangers for high pressure and temperature applications are realized by brazing or by diffusion bonding. In the first case, brazing pastes are used containing Cu and Ni, which undergo corrosion phenomena in the presence of ammonia. In the second case, plates have to be assembled using a paste with a composition similar to the plates' metal but with lower melting temperature. In the two cases, long thermal treatments are required in order to obtain the final component. Also by the mean of software for thermodynamic and properties calculations, we designed a ferritic alloy suitable for applications in highly corrosive alkaline environments. The alloy has been produced by Vacuum Induction Melting (VIM) process and microstructural (SEM, XRD), mechanical, thermal and corrosion investigations have been performed. Moreover, considering the high potentialities of Additive Manufacturing (AM) in the realization of components with complex geometries, even with internal channels, in reducing waste material and potentially reducing energy production consumption, we produced the alloy by gas atomization and we realized small cubic samples by DMLS process. The experimental results demonstrated that the alloy presents a suitable corrosion resistance, up to 150°C, in ammonia-water solution, a thermal conductivity higher than double that of stainless steel and that it can be used to realize heat exchangers by AM processes. The activity is funded by the Program Agreements with the Italian Ministry of Economic Development "Advanced materials for energy".

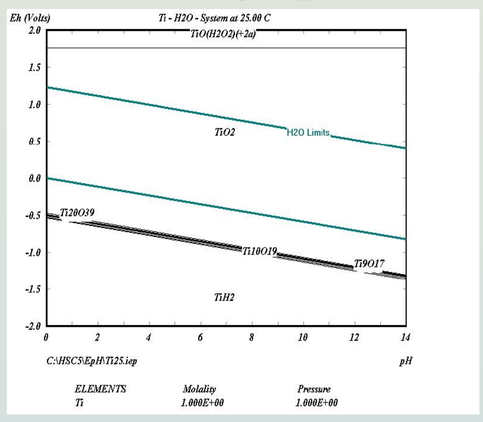
Corrosion

Pourbaix diagrams, tension-pH, allow to describe the theoretical behaviour of chemical elements in aqueous solutions at different temperature and pressure. $NH_3+H_2O \Leftrightarrow NH_4^+ + OH^-$

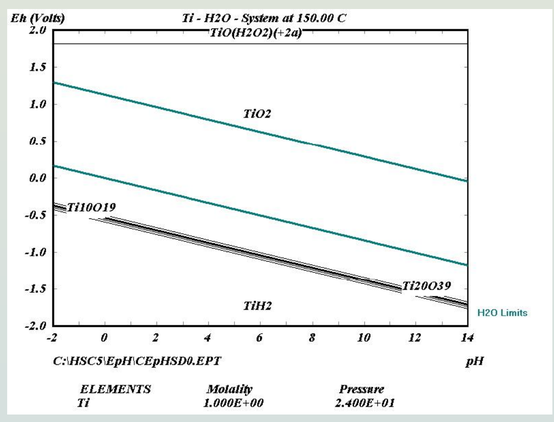
The code HSC_5 developed in HSC-Chemistry software has been used to calculate Pourbaix diagrams



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

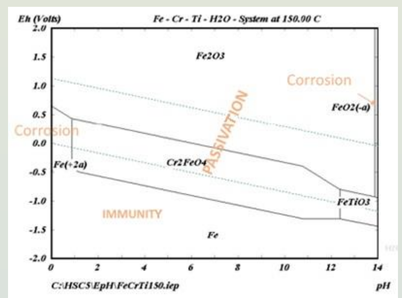


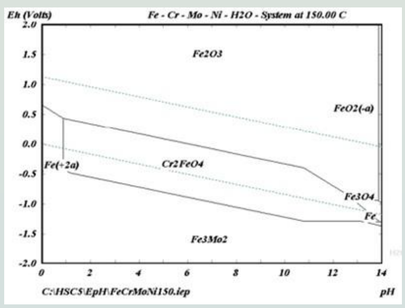
Calculated Pourbaix diagram of Ti in aqueous solution at 25°C and atmospheric pressure



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

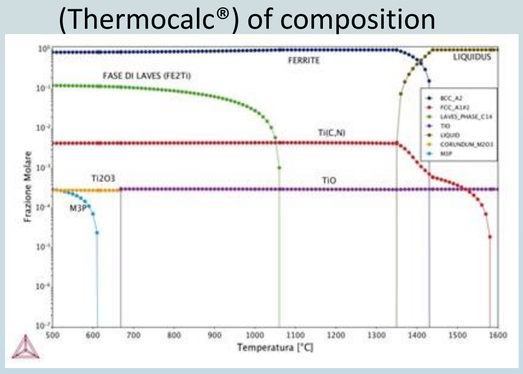




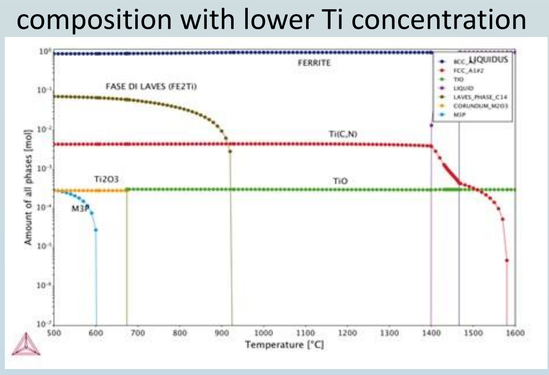
Calculated Pourbaix diagram of Fe-Cr-Mo-Ni in aqueous solution at 25°C and atmospheric pressure (AISI 316)

Thermodynamical studies and alloy specifications

Stepped Calculation Graph (Thermocalc®) of composition

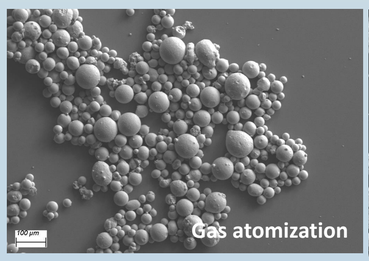


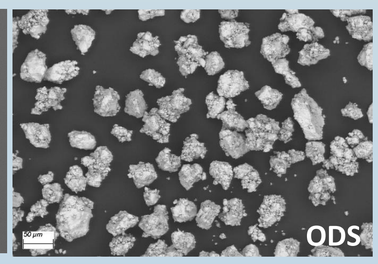
Stepped Calculation Graph (Thermocalc®) of composition with lower Ti concentration



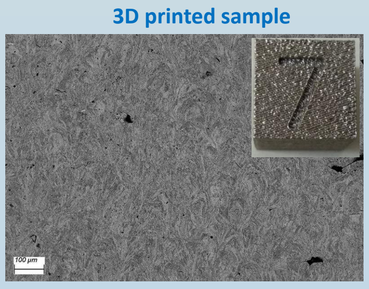
- A new ferritic alloy has been designed with the aim of realizing by 3D printing the heat exchangers for absorption machines;
- Ferritic steels have generally higher thermal conductivity respect to austenitic stainless steels generally used for this type of heat exchangers;
- lower linear expansion coefficient respect to austenitic steels (reduction of thermo-mechanical fatigue);
- Lower alloy costs due to nickel, molybdenum and chromium content reduction

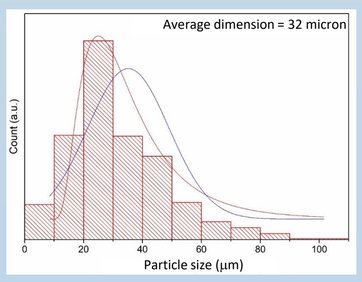
- Production of bulk material (a bar): Vacuum Induction Melting (VIM);
- Production of spherical powder particles: Electrode induction melting Inert Gas Atomization (EIGA);
- Properties of ferritic steel produced:
  - an higher thermal conductivity respect to AISI 316;
  - linear expansion coefficient 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.

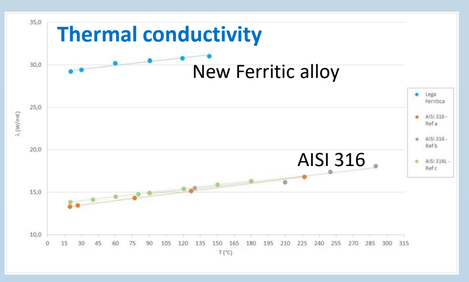


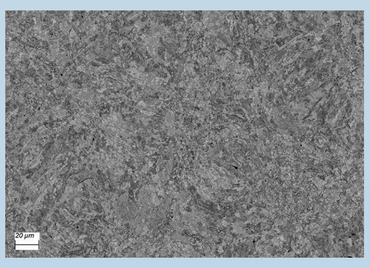


3D printed sample









Conclusions: Additive manufacturing is a suitable to realize components even with highly convoluted internal channels as heat exchangers. New challenges have arisen related to the development of materials for AM processes. A ferritic alloy has been designed and produced by VIM and gas atomization. The alloy presents 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