Structural Analysis of a Pressure Sensor for High Temperature Environments

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Abstract

Introduction: Important sectors of aerospace, automobile and energy industries require sensors that can provide reliable measurements in high temperature environments. Sensors operating at the temperature higher that 500 °C are absent in the world market. Our goal is to develop a pressure sensor that can operate at the high temperature up to 700 °C. Our sensor will be made up of a ceramic sensible element and a metallic case. The sensible element will be a ceramic beam with a Weathstone bridge on its surface. A CAD representation of a section of our design is in Figure 1. The gas, entering the lower part of the sensor will warp a plate with thickness 0.5 mm, pushing a pole. The end of the sensible element, with an end fastened to the top of the pole, will undergo an s-shape bending. Figure 2 shows a COMSOL elaboration of the stress tensor on the surface of the sensible element. In Figure 2 we have encircled two areas: the blue represents the maximum compressive stress, the red the maximum tensile stress. In each region the stress is uniform. In this simulation we chose Al2O3 as material of the beam. The bridge resistors will set up in these two regions and connected to sum the changes of their resistances. Use of COMSOL Multiphysics: A structural analysis on the case has been performed to design the case and to study the behavior with pressure and temperature of different metallic alloys, Steel 316L, Inconel 718 and Ti6Al4V; all of them largely used in aeronautics. This analysis was performed using a model reckoning with the mechanical stress due the pressure combined with the thermal expansion of the material. In particular the displacement of the top of the pole and the stress on the membrane were investigated. The results of the stress were compared to the Yield Strength [1,2,3] of the considered alloys in order to calculate the factor of safety. Results: The displacement grows linearly with the pressure at any temperature with similar rates. But the stresses on the plate grows with pressure and with temperature. In Figure 3 is showed the graphs of the maximum stress on the plate as a function of pressure calculated with COMSOL for a room temperature of 700 °C. Comparing these values with the yield strength at the same temperature we obtained the results showed in Figure 4 for the factor of safety. Conclusion: At high temperature the FoS of the steel is lower than 1, even with a pressure of 0 Pa, because of its low value of yield strength, the mechanical stress due to thermal expansion is over the elastic limit. The Nickel and Titanium alloys have both good behavior. The Inconel results having a better FoS even at high pressure, but the Ti6Al4V exhibits higher values of displacement with growing pressures and then could be useful for a higher sensibility of the sensor.

Reference

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2. Special Metals Corporation, Product Reference Guide, 2007
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http://dspace.uniroma2.it/dspace/bitstream/2108/857/7/Chapter+5.pdf.

Figures used in the abstract

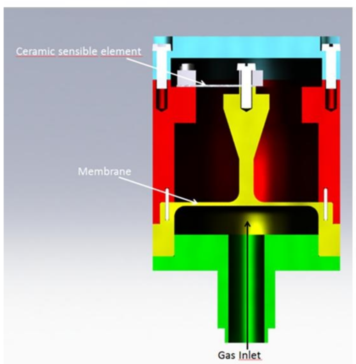

Figure 1: Section of the CAD design of the sensor.

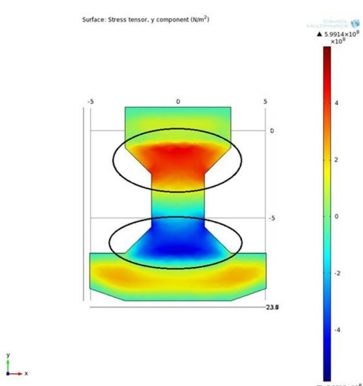

Figure 2: y component (longitudinal dimension) of the stress tensor calculated with COMSOL.

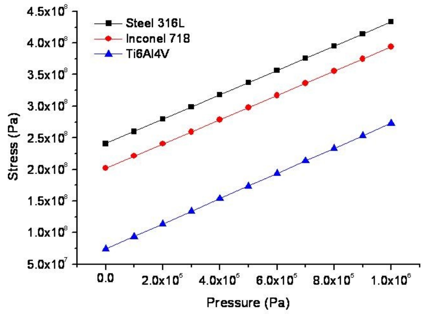

Figure 3: Stress vs. pressure, T=700 °C.

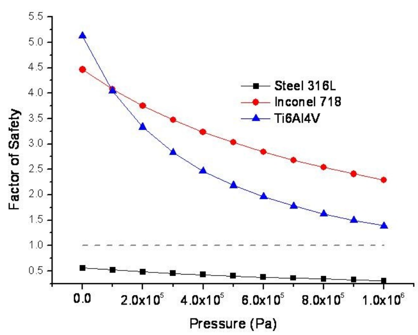

Figure 4: FoS vs. pressure calculated for the three alloys, T=700 °C.