CRACKS FORMATION ON EXHAUST DUCTS FOR NAVAL GAS TURBINES: RESEARCH ON CAUSES AND USE OF A NEW CR-MN AUSTENITIC STAINLESS STEEL

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ABSTRACT

It has been noticed the occurrence of nucleation and cracks propagation trough the walls of the exhaust ducts for naval gas turbines. Studies performed earlier shown that the thermal shock loading together with the normal service loadings has influence in this phenomena [R.F. Martins, C. Moura Branco, A.M.Gonçalves-Coelho, Edgar C. Gomes 2008]. In order to prevent the fatigue crack propagation that was verified in service [R.F. Martins, C. Moura Branco, A.M.Gonçalves-Coelho, Edgar C. Gomes 2008], a recently developed ultrahigh-strength austenitic stainless steel was selected (Cr-Mn steel - number 1.4376) and its mechanical properties are under study. This new material could replace, locally, the current material used in the main structure of the exhaust duct.

The exhaust system is approximately 14m high and has a cross section which varies between 1.56x1.02m at the inlet and 2.6x2m at the exit. The combustion products as well as fresh air comes from a box where the turbine stands, the mixture between the two mass flows is made near the turbine outlet. The current material used in the main structure of the exhaust system is a austenitic stainless steel from the AISI 300 series (AISI 316L), it has a thickness of proximally 3.7mm and it is thermally insulated with rockwool with proximally 200 mm of thickness.

There is few information published about the temperatures through this system, even so there is a reference to one punctual value for the temperature of the external face of the internal wall, measured at the critical locations, of 350ºC [Martins, R.F. 2005]. From the information given by the gas turbine supplier it is estimated that the mass flow rate of the combustion products at the exit of the turbine is about 59 $^{kg}/_{s}$ with a temperature of about 566ºC. The secondary mass flow rate, of fresh air, is about with 9 $^{kg}/_{s}$ a temperature of about 85ºC.

The main objective of this research is to explain the cause of the cracks occurrence and to propose new replacement materials. In order to obtain the temperature and pressure conditions that the steel duct is exposed measurements were carried out and a complementary CFD simulation of the internal exhaust flow was carried out.

The AISI 300 series are ternary alloys of Fe-Cr-Ni, containing about 16% to 25% of Cr and 7% to 20% of Ni. Its microstructure is austenitic, which is a face centered cubic crystaline type (CFC). While

offering a good corrosion resistance, these alloys when welded or cooled slowly from high temperatures, may become susceptible to intergranular corrosion by the precipitation of chromium carbides in grain boundaries [European Prestandard ENV 1993-1-4:1996]. This feature can be overcome by the addition of stabilizing alloy elements, such as titanium (Ti) or niobium (Nb) and/or ensuring that the content of carbon (C) is less than 0.03% [European Prestandard ENV 1993-1-4:1996]. The addition of molybdenum (Mo) increases the resistance to pitting corrosion.

The recently developed Cr-Mn austenitic stainless steel has good mechanical properties [Information on http://www.nirosta.de/Material.45.0.html?&L=1], but has not been extensively studied and references in the literature to it are scarce.

In order to study the mechanical properties of both materials, current AISI 316L stainless steel and Cr-Mn austenitic stainless steel, uniaxial tensile tests were performed for two different temperatures, the ambient temperature and 350ºC. This last value was given by the numerical and experimental analysis.

Based in [NP EN 10 002-1:1990 and ISO Recommendation 1969], specimens with the geometry shown in Fig. 1 were manufactured and submitted to uniaxial tensile tests at room temperature and at 350ºC.

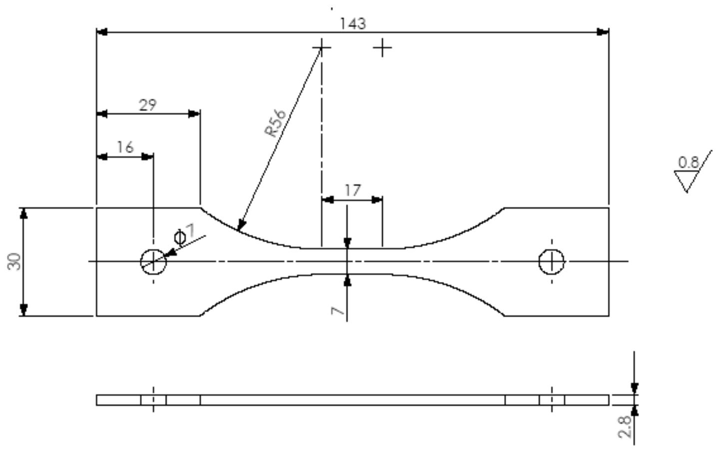

Figure 1. Specimen geometry for uniaxial tensile tests

The CFD analysis (calculation of pressure, velocity and temperature fields) of the exhaust combustion products that flows through the exhaust system under study, Fig.2, was carried out using the computer freeware code FDS (Fire Dynamics Simulator). FDS is a Computational Fluid Dynamics (CFD) model of fire-driven fluid flow. The model solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow. The partial derivatives of the conservation equations of mass, momentum and energy are approximated as finite differences, and the solution is updated in time on a three-dimensional, rectilinear grid. Turbulence is treated by means of a Smagorinsky form of Large Eddy Simulation (LES). Thermal radiation is computed using a finite volume technique on the same grid as the flow solver. In the interface fluid-solid and in the boundary-layer flow, the gradients of velocity and temperature are high and requires the use of wall functions, as well as a refined mesh, while in the areas of fluid, a more sparse mesh was used, Fig.2. The two different mass flows were imposed through two boundary conditions.

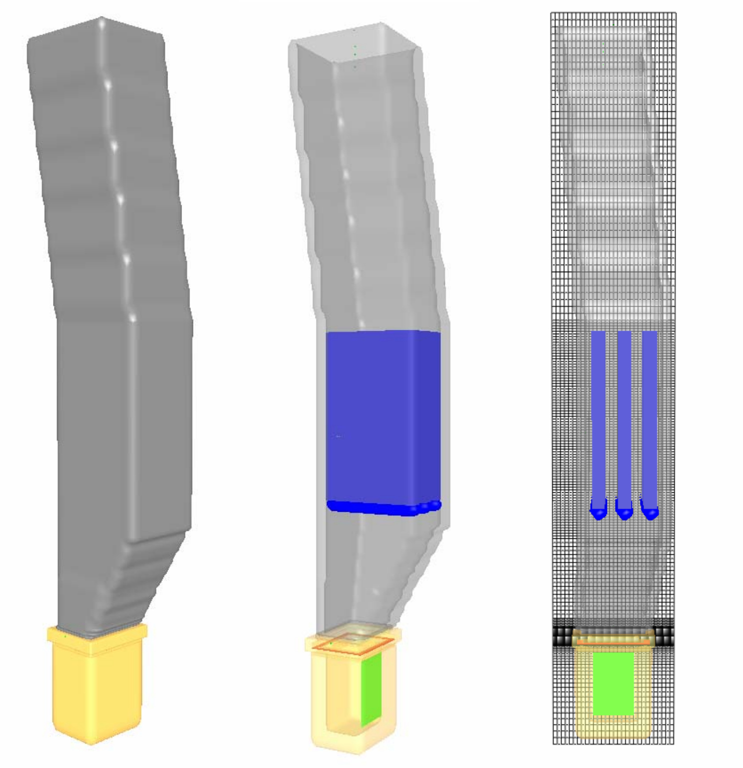

Figure 2. Geometry and mesh used in the CFD analysis

With purpose of getting experimental values of temperature and velocities in the real system one of the ships using this turbine was monitored. Six thermocouples were installed in the local where cracks occur , Fig.3, and the exit velocity was measured using one pitot tube in the outlet of the exhaust duct.

Figure 3. Thermocouples installed in the duct

In this paper the CFD numerical results obtained in the previous studies [H.J.T. Cruz 2008 and H.J.T. Cruz, Aveiro, J.L., Viegas, J.C. e Martins, R.F. 2009] are compared with the experimental results measured on board of a ship using this exhaust system. CFD simulations are validated with experimental results and these simulations give complementary information on temperature and flow pressure at the critical localizations. In a final analysis it is intended to determine if the new material would be appropriate to replace locally the current AISI 316L stainless steel.

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