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Research article
MATERIALS & FABRICATION

Determining Properties of Materials at High Temperatures

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SUMMARY

This article highlights the importance of integrating time-limited micro structural changes and local material properties when sizing structural parts at high temperatures. It also reviews different technological solutions found in the literature while presenting their limits every time. Finally, the article describes the overall goal and the methodology used to reach it.

Editor's Note

This article discusses the challenges of conducting high temperature tensile tests and the methodology leading to the design of a micromachine that can perform tensile tests in a controlled atmosphere. A second article entitled *Hot Tensile Strength Micromachine for Aeronautics* will present the micromachine that was designed.

Introduction

The growing interest in maximizing design space and high-temperature structural performance in various industrial sectors (aeronautics, aerospace, energy, waste management) introduces the need to develop new materials, but also to better understand the behaviour of materials at high temperatures under different scales, from structural to micro structural [1]. In fact, some parts like jet engines have to withstand very high temperatures (above 1200°C) while exhibiting good durability in relatively challenging atmospheres [2]. Characterizing, modelling, simulating and predicting mechanical responses of materials at high temperatures and at increasingly finer scales have become the main objectives of industrial and academic communities.

The materials subjected to external stresses (temperature, mechanical loading, environment) evolve over time [3]. Therefore, it is essential to integrate micro structural evolution and local mechanical properties into the sizing of parts or structural components. The experimental characterization of materials is difficult at such micro structural gradient scales and properties, especially at high temperatures. To obtain the material data, or design data, mechanical tests must be carried out on samples sized to the gradient of microstructures and properties, in other words, on micron-sized samples (a few microns thick), but also on samples of conventional size (a few millimetres thick). This brings the need to develop multi-scale characterization benches in order to supply the models with sizing, behaviour and lifetime predictions, thus obtaining local properties of materials that evolve over time. Testing such thin materials in this temperature range (from room temperature to temperatures around 1200°C) by controlling atmospheric effects is a serious challenge.

Atmosphere-Controlled Test Benches


Figure 1 Example of a completely enclosed system allowing testing under controlled atmosphere.

This issue (characterizing materials at high temperatures using ultra-thin samples) has been the subject of some test bench developments since the early 2000s [4] (Professor K.J. Hemker and team, John Hopkins University) [5]. Adapting the tools used in high-temperature micro-optoelectronic characterization laid the groundwork for the characterization of so-called freestanding samples at more than 1000°C through Joule heating (sample thickness ranging from 10 to 100 microns and several hundred microns in width). Similar test benches were set up by Alam *et al*. [1] to carry out uniaxial tests on refractory alloys, from room temperature up to 1200°C, with strain rates ranging from 10^{-5} to $10^{-1}s^{-1}$.

Joule heating facilitates access to the test tube (no heating elements around the sample), in order to couple different complementary techniques (optical devices to monitor deformation, thermal imaging cameras for temperature mapping, etc.). This technique ensures easy use of complementary techniques. However, Joule heating is highly sensitive to variations in effective cross-sections and to damage caused by mechanical testing. Therefore, this technique demonstrates major limits in the presence of test tube necking or in localizing the deformation and damage development, but also because of the range of materials that can be tested, in other words, conductive materials. The recent creation of atmosphere-controlled micro mechanical characterization benches using infrared lamp furnace heating has overcome the thermal limitations associated with sample deformations during mechanical testing [6, 7]. The test benches had the advantage of enabling tests at very high temperatures (beyond 1100°C), under controlled atmosphere. A detailed view of this micromachine is shown in Figure 2.

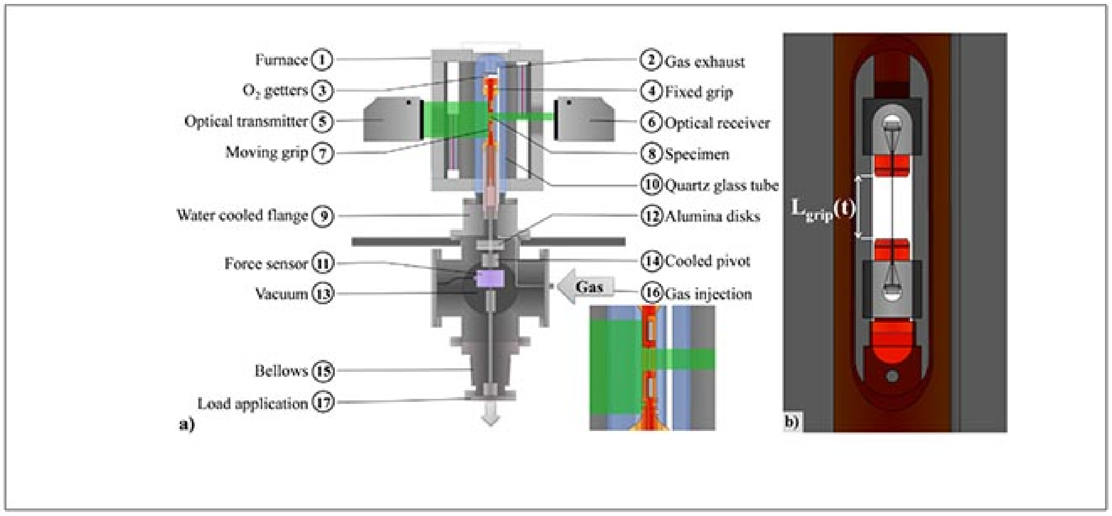

Figure 2 Micromachine designed during the research work of Texier et al. [6]. a) Detailed view of the design assembly, b) View of the mooring housing the micro test tube.

However, designing this type of micromachine has its limits in relation to the need we would like to fulfill with this research with regard to corrosive atmospheres. In addition, the design solution does not allow easy handling in installing ultra-thin samples, requiring great dexterity. Nevertheless, this study removed scientific and technological barriers and was able to demonstrate the feasibility of this type of mechanical testing, although challenging in its execution, concerning aeronautical coatings and their impact on the substrate [8, 9].

Micromachine Design Methodology

Therefore, despite the limitations described in the literature, this research project proposes the development of a micro-mechanical characterization prototype to carry out high temperature tests (up to 1200°C) on all types of materials, under controlled atmosphere (neutral, corrosive or oxidizing). The instrumentation used for this micromachine will also conduct contactless macroscopic and local deformation monitoring on the sample, using recent techniques applied to photo mechanics.

This research is part of the OGFPA project (PSR-PSIIRI 954 – Part 4), funded by Québec's *Ministère de l'Économie, de la Science et de l'Innovation* (MESI), led by ETS Professor Philippe Bocher. The test bench development is the subject of a master's research project directed by James William Chuitcheu IV Tchouambe. The project is carried out in close collaboration with Jean-Marc Zisa, director of Instruments Innovatorr Inc. and Intercovamex, and with Damien Texier, CNRS researcher at the Clément Ader Institute.

After drafting the complete technological specifications required, the adopted functional analysis is detailed below (Figure 3):

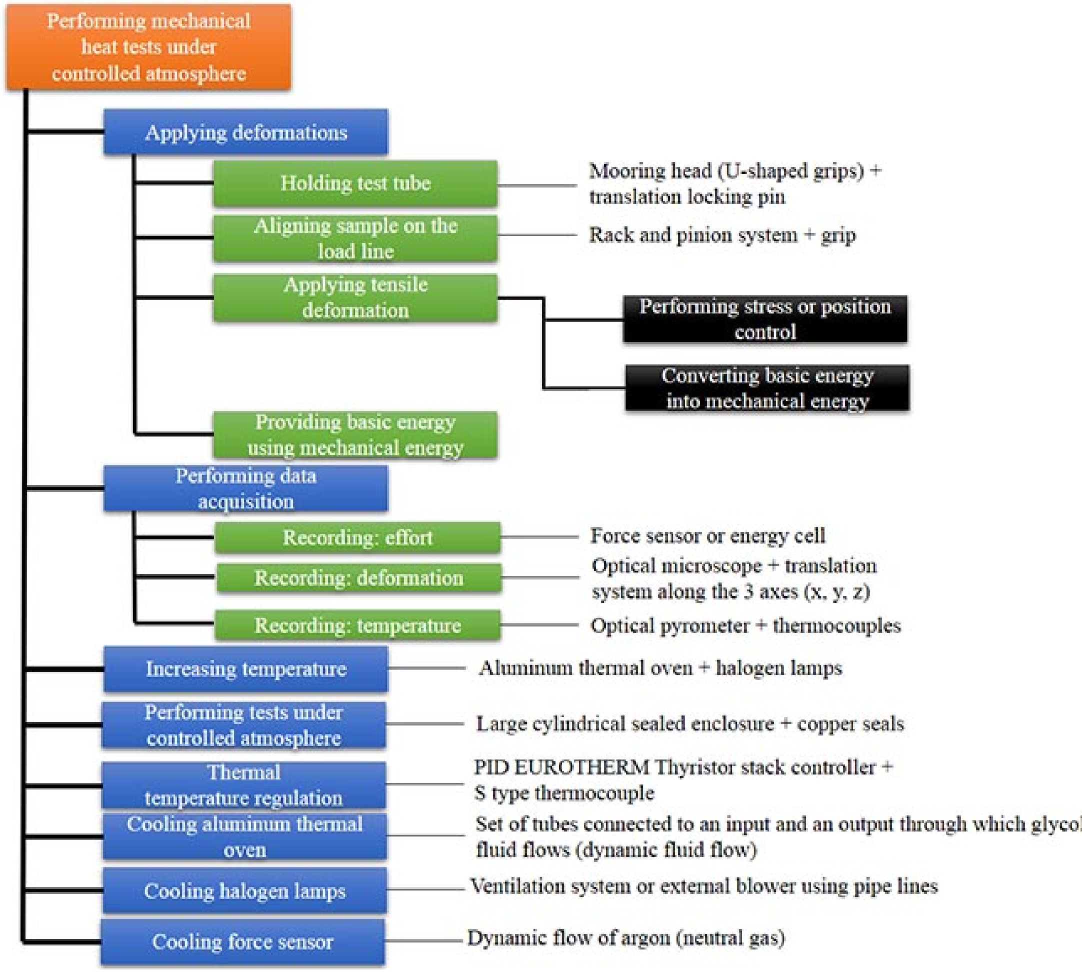

Figure 3 Functional analysis of the hot tensile strength micromachine under controlled atmosphere

In order to meet the requirements contained in this functional analysis, the selected methodology is summarized in the figure below (Figure 4):

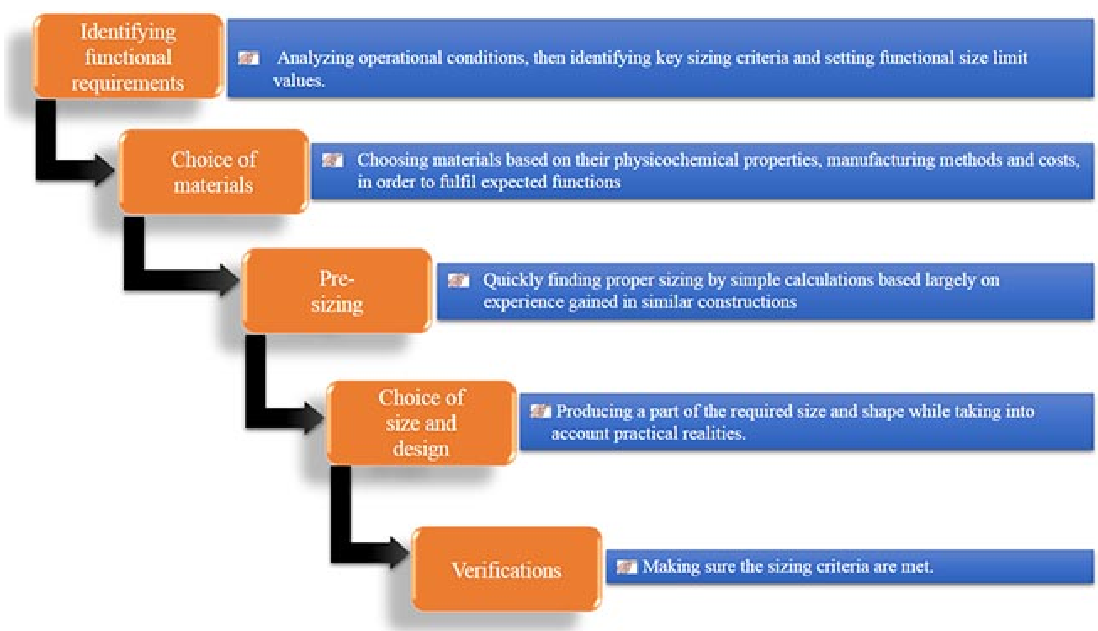

Figure 4 Sizing methodology for a hot tensile strength micromachine under controlled atmosphere

To Be Continued

The resulting micromachine will be presented in an upcoming article entitled *Hot Tensile Strength Micromachine for Aeronautics.*

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Images references