Defense Systems Information Analysis Center

DSIAC TECHNICAL INQUIRY (TI) RESPONSE REPORT

Commercially Available Materials to Resist Compressive Creep at 400 °C

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The Defense Systems Information Analysis Center (DSIAC) received a technical inquiry requesting information in identifying a mental with high creep resistance. The inquirer stated that there was a lack of publicly available information pertaining to creep and creep testing results. The desired application required material stability in the 400 °C range. A secondary concern for the application was thermal conductivity; a tertiary concern was material density. The inquirer requested direction for testing results or material recommendations. Subject matter experts at DSIAC provided a set of materials recommendations and caveats based on the results of their research.

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A chief service of the DoD IACs is free technical inquiry (TI) research, limited to 4 research hours per inquiry. This TI response report summarizes the research findings of one such inquiry jointly conducted by DSIAC.

ABSTRACT

The Defense Systems Information Analysis Center (DSIAC) received a technical inquiry requesting information in identifying a mental with high creep resistance. The inquirer stated that there was a lack of publicly available information pertaining to creep and creep testing results. The desired application required material stability in the 400 °C range. A secondary concern for the application was thermal conductivity; a tertiary concern was material density. The inquirer requested direction for testing results or material recommendations. Subject matter experts at DSIAC provided a set of materials recommendations and caveats based on the results of their research.

Contents

List of Figures

1.0 TI Request

1.1 INQUIRY

What metals (if any) have a high creep resistance and material stability in the 400 °C range?

1.2 DESCRIPTION

The inquirer requested information on materials with high creep resistance. Further discussions revolved around existing options (such as those used in high-temperature aircraft engines) and what degree of creep resistance was required.

The inquirer stated that the material requirements were not as extreme as what might be encountered in the hot section of a jet engine (which can require the use of single crystal superalloy material to avoid creep and fatigue). The inquirer embarked on a small test campaign subjecting several coupons to low compressive stresses at ~400 °C for an extended time. Results initially showed that for a baseline of 7 ksi, one material resulted in 5% deformation per hour. Several materials performed significantly better. However, this number was shown to be incredibly sensitive to the stress applied. The inquirer was curious as to if there was a way to convert this into a more concise representation of the material's creep resistance. For a target, any commercially available materials that would yield <1%/hr at 7 ksi would be preferred.

2.0 TI Response

2.1 CREEP OVERVIEW

Creep in metals is a complicated property that depends on both temperature and stress; it is a nonlinear process. Effects of creep are further complicated by the fact that metals may undergo second-order phase transitions as a result of pressure, temperature, and time. Aging and working history also affect these measurements. It is difficult for a metals producer to measure the creep across all possible combinations of all parameters. Material processing (microstructure) has a significant effect on the creep properties (see Figure 1). As a result, identifying useful and complete information on a particular material is not readily available in a database form.

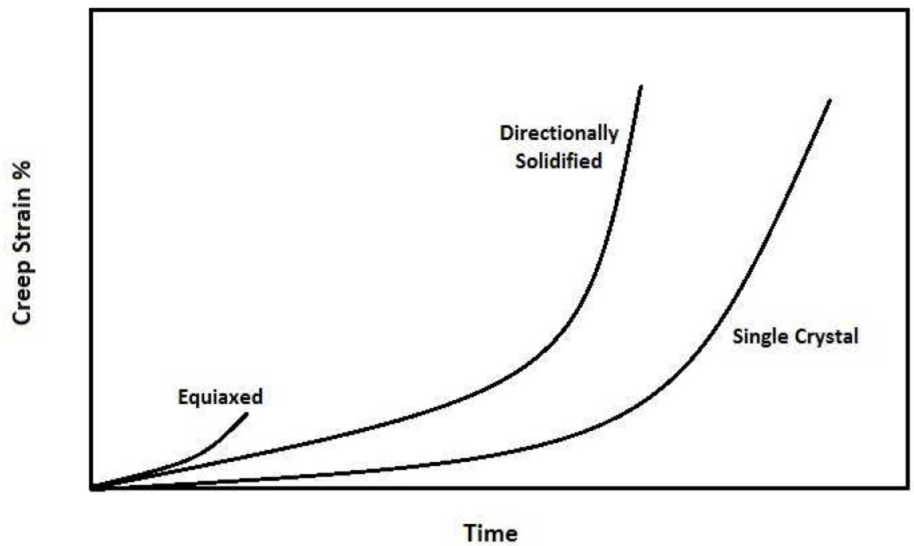

Figure 1: Effect of Microstructure Properties on Creep Strain [1].

The **Larson–Miller parameter** is one means to predict the lifetime of material vs. time and temperature using a correlative approach based on the Arrhenius rate equation. The value of the parameter is usually expressed as follows:

$$LMP = T(C + \log t),$$

where C is a material-specific constant, often approximated as 20; t is the time in hours; and T is the temperature in K.

Creep-stress rupture data for high-temperature, creep-resistant alloys are often plotted as log stress to rupture vs. a combination of log time to rupture and temperature. As the requestor desired publicly available information, much of the response to this technical inquiry is available in the form of internet search links.

Several legacy technical reports provide a good background on creep fundamentals and how it has been measured. Instrumentation has significantly improved over the years, but the basics are the same. This report compares compressive creep vs. tensile creep, which are not the same [2], and cites some relevant standards from the timeframe it was published. The second report [3] explicitly measures compressive creep in aluminum at elevated temperatures. We note that a creep rate in excess of 1%/hr is better described as material flow rather than material creep. In Carlson and Schwope [3], at 300 °F (~150 °C) and an applied compressive stress of 36 ksi, the compressive creep was 250/1,000,000 (or) 0.025% at 200 hr. In most cases, tensile creep is larger than compressive creep. Tensile strength is a material property that is commonly provided by producers via testing. If a metal has a high tensile strength, especially at the target temperature of 400 °C, this is a good indicator that the material in question is a good candidate for use as a creep material and is suitable for further testing, which appears to be the best means to determine material performance.

The requestor is seeking advice on suitable commercial materials with creep of <1%/hr at 7 ksi at 400 °C. The stress is modest. Depending on the material and time spent at this level, 400 °C is in the range where some materials may be annealed or aged. For this reason, materials typically used in gas turbine engines may offer the best path forward. These materials are well characterized at elevated temperatures and commercially available. Note that the predominant stress in turbine engines is the centripetal force associated with spinning compressor or turbine blades, which manifests as a tensile stress. Depending on the location in the engine (i.e., compressor or turbine), either Ti alloys or Ni-based superalloys are used, respectively. Ni-based superalloys have extreme temperature performance but a high density [4]. Ti alloys are favored, when possible, due to their light weight and commercial availability. Improvements in the performance of these is ongoing [5–7], with attempts to drive down the density of these materials while simultaneously maintaining or increasing the creep resistance.

2.2 TI-BASED ALLOY OPTIONS

Recent research indicates that higher concentrations of Ti in these alloys can extend the range of temperatures at which they remain stable. A good review with many references of materials used in jet engines is given in Okura [8]. Gas turbines [1] also expose components to extreme stress at high temperatures. From a recent paper on high-temperature alloys, data appears to show that a Ti-based alloy may provide the best optimization of creep temperature and strength resistance while offering modest thermal/electrical conductivity and density [9]. We do note that if higher temperatures (>600 °C) are used, it is possible for oxidization to become a problem. Also, depending on the alloy of Ti used and the temperature and time at temperature, it is possible that α-case surface embrittlement may become an issue as well. Recent results show that an alloy such as Ti-1100 or Ti-834 may provide the best option.

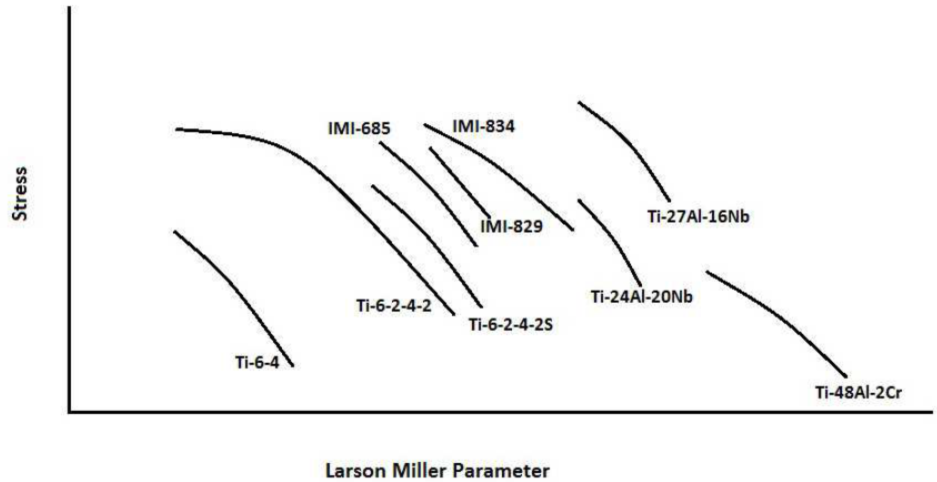

Figure 2: Larson Miller Parameter Ranges for Ti-Based Alloys [1].

2.3 NI-BASED ALLOY OPTIONS

In our research, we found a source of many high-performance alloys (superalloys) at HPAlloy [10]. There are several suppliers of high-temperature titanium alloy. We also found a company in England which does commercial creep testing [11]. Given this company-wide portfolio, they might already have useful information on high-performance alloys that may not be published. We do note that although the Ni-based superalloys will likely provide superior creep resistance, their density is substantially more than Ti-based options.

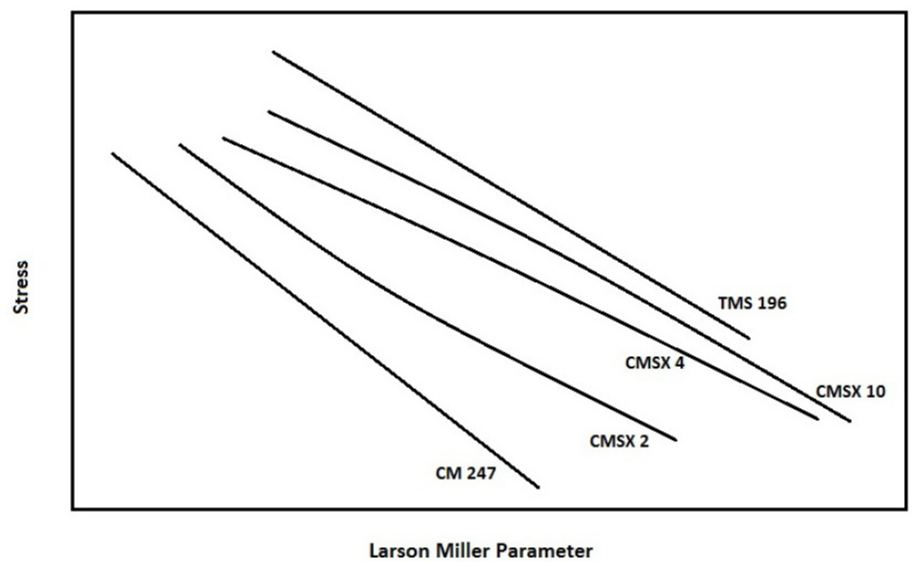

Figure 3: Larson Miller Parameter Ranges for Ni-Based Alloys [1].

3.0 Summary

The most optimized solution appears to be a high-temperature Ti alloy. Because there are quite a few out there and some are better than others, market research is required. One website that has been used by these researchers is titaniumjoe.com—this organization provides randomly sized drops from larger Ti pieces in several various alloys.

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BIOGRAPHIES

Richard Piner is a research engineer at Texas Research Institute (TRI) Austin, Inc. He has over 48 years of industry experience spanning a wide variety of technical topics, including, but not limited to, the four broad categories of reactors, graphene, graphene oxide, and scanning microscopy techniques. He has hundreds of scholarly publications yielding over 40,000 citations to his work. Dr. Piner holds B.S., M.S., and a Ph.D. in physics as well as a B.S. in mathematics from Purdue University, where he studied scanning tunneling microscopy.

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