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# Design of creep machine and creep specimen chamber for carrying out creep tests in flowing liquid sodium

S. Ravi*, K. Laha, S. Sakthy, M.D. Mathew, T. Jayakumar

*Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam 603102, India*

## HIGHLIGHTS

- Design of a lever type creep machine for carrying out creep test in flowing sodium.
- Leveling of lever during creep was achieved by automated movement of fulcrum.
- Design of creep chamber for providing constant sodium flow rate across creep specimen.
- Minimum use of bellow in chamber for sodium containment and mechanical isolation.
- Mini-lever mechanism to counter balance load reduction on specimen due to bellow stiffness.

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## ABSTRACT

A creep testing system has been designed, fabricated, installed and validated for carrying out creep tests in flowing liquid sodium. The testing system consists of two sections namely creep testing machine and an environmental chamber. The testing system has the ability of (i) applying tensile load to the test specimen through a lever, (ii) monitoring continuously the creep elongation and (iii) allowing sodium to flow around the creep specimen at constant velocity. The annular space between the creep specimen and the environmental chamber has been suitably designed to maintain constant sodium flow velocity. Primary and secondary bellows are employed in the environmental chamber to (i) mechanically isolate the creep specimen, (ii) prevent the flowing sodium in contact with air and (iii) maintain an argon gas cover to the leaking sodium if any from primary bellow, with a provision to an alarm get activated by a spark plug. The lever-horizontality during creep test has been maintained by automatically lifting up the fulcrum instead of lowering down the pull rod as conventionally used. A mini lever mechanism has been incorporated in the load train to counter balance the load reduction on specimen from the changing stiffness of the bellows. The validation of the testing system has been established by carrying out creep tests on 316L(N) stainless steel at 873 K over a wide stress range and comparing the results with those obtained in air by employing the developed and conventional creep testing machines.



## 1. Introduction

Liquid metal environmental effect on high temperature mechanical properties of structural materials is one of the key uncertain factors in the design of Liquid Metal Fast Breeder Reactor (LMFBR). Although a great deal of information on mechanical properties of the structural materials in air environment is available, their use in LMFBR may pose unique long-term environmental interaction problem for which adequate data do not currently adequately exist. The materials used in LMFBR must be able to withstand the operating condition of steady and fluctuating as well as transient stresses during start-up and shut-down for design life of 40 years and beyond, at high temperatures in the range 723–873 K in the dynamic liquid sodium environment. Austenitic stainless steels are generally used to fabricate the structural components of the fast reactor with liquid sodium as coolant. Austenitic stainless steels usually undergo microstructural changes on long-term exposure at high temperature and stresses which affects their mechanical properties and corrosion resistances. The liquid metal can greatly influence the mechanical properties of the steel. A guideline is needed to incorporate the environmental effects in the design rules to improve the performance reliability over long operating time.

In sodium cooled fast breeder reactors (FBRs), the operating stress and temperature conditions are complex and interactions between creep deformation with environment may significantly alter the creep rupture strength. The influence of liquid sodium on the mechanical properties especially creep, fatigue and

* Corresponding author. Tel.: +91 44 27480500x21051; fax: +91 44 27480075.
*E-mail address:* sravi@igcar.gov.in (S. Ravi).

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creep-fatigue interaction has drawn worldwide attention. Therefore, it has assumed greater importance particularly with respect to long-term creep properties (Leea et al., 2012; Date et al., 2008; Kannan et al., 2011; Wakai et al., 2008; Lee et al., 2013). The creep rupture life of the austenitic stainless steels can be affected by carburization or decarburization of the steel in the flowing sodium due to mass transfer (Yoshida et al., 1995; Snyder, 1976; Sandusky et al., 1973), leaching of the elements (Furukawa et al., 2009), protection of the specimen from oxidation and also from the intergranular embrittlement effects (Mishra, 1993), degree of which depends on the sodium purity and carbon activity in liquid sodium and the type of steel (Tai Asayama, 2001). Various reviews relating to the effect of flowing sodium environment on mechanical properties of austenitic stainless steels, particularly with respect to types 304 SS and 316L SS have been published in the open literature (Borgstedt and Huthmann, 1991). However, the available information on types 304 and 316L austenitic stainless steels do not present a coherent picture of the effects of the sodium environment on mechanical properties. The results obtained from various laboratories have been found to exhibit significant variations (Kannan, 2009; Hiroshi, 2001; Ukai, 2000; Mishra, 1997). Furthermore, almost negligible data exits on the properties of modified type 316L (N) SS as influenced by the sodium environment. Special skill and knowledge are required to perform creep tests under flowing sodium environment, considering the safety aspects. Conventional creep machine with environmental creep specimen chamber cannot be used to perform creep tests in flowing sodium.

In this paper, design of a creep testing system comprising a lever type creep machine with auto adjustable fulcrum to maintain lever horizontality and double-bellow creep specimen environmental chamber with safety features for carrying out creep test in flowing sodium has been presented. A new concept has also been incorporated in the testing system to counter balance the reduction in load in specimen from the stiffness of bellows, as the specimen elongates during creep.

## 2. Background of creep testing machine

A brief background of creep testing system is described in this section. Particular attention has been paid to the general nature of creep rupture testing system having environmental chamber to facilitate creep test in controlled environment.

### *2.1. General features of creep testing machine for carrying out creep tests in controlled environment*

In a conventional creep testing system for carrying out creep test in air, the creep specimen is loaded by dead weight through a class 1 lever having fixed lever ratio, mounted on a rigid frame (Fig. 1). The specimen is attached to the load train through universal couplings. As the specimen elongates during creep test, the lever horizontality gets disturbed which changes the lever ratio as well as the vertical axiality of the test specimen. The lower end of the load train is connected to a motorized draw head which pulls down the load train to bring back the lever to the horizontal position. The draw head motor is activated by a sensor in the event of deviation of the horizontality of the lever due to specimen elongation and thus the lever horizontality is maintained throughout the creep test.

Temperature along the gauge section of the creep specimen is maintained within $\pm 2$ K throughout the creep test by a three-zone resistive furnace. The temperature across the creep specimen is monitored by three thermocouples attached along the gauge length of the creep specimen. PID controllers with power supply units are employed to control temperature in each heating zone of the furnace to maintain uniform temperature across the specimen. Elongation of the creep specimen during creep test is monitored by an extensometer and LVDT/digital dial indicator attachment. Temperature of the specimen and its elongation are logged throughout the creep tests using a data logger. In the event of failure of the creep specimen, provision for automatic shutdown of the machine is being provided.

Creep test in controlled static-gas/vacuum atmosphere is being carried out by attaching an environmental chamber to the conventional creep machine, as shown in Fig. 2. Mechanical isolation of the creep specimen from the chamber has been achieved by providing bellows at both ends of the chamber so that the specimen can elongate relatively freely during creep test. Bellows are fixed with the load train by O-rings to ensure leak tightness. Water jackets are provided to cool ends of the environmental chamber to avoid damage to the O-ring by heat. Extensometer along with LVDT/digital dial indicator is directly attached with the creep specimen inside the environmental chamber. The signal from the LVDT/digital dial indicator is taken out from the chamber through sealed plug mounted on the bottom flange of the chamber. As in the creep machine for conducting creep test in air environment, temperature of the creep specimen is monitored by three thermocouples tied along the specimen length. Signals from the thermocouples are taken out from the chamber through the sealed plug fixed at the bottom flange of the chamber. Loading the creep specimen, logging the elongation and temperature data and the safe shutdown of the machine on failure of creep specimen are being performed as in the conventional creep testing machine.

### *2.2. Drawbacks of conventional creep testing system for carrying out creep test in flowing liquid sodium*

Adaptation of the conventional creep testing machine for carrying out creep in flowing liquid sodium has the following drawbacks:

- Specified flow rate of liquid sodium across the specimen cannot be maintained in the conventional creep machine with environmental chamber.
- Both the bellows will be exposed to liquid sodium directly. Moreover the lower bellow is subjected to carry the entire load of the liquid sodium column above it in the environmental chamber. This will change the stiffness of the bellow and the bellow may rupture under load from the liquid sodium column.
- Even metallic O-ring or metallic gasket to connect the bellow with the load train is not suitable in liquid sodium environment since they may get relaxed during high temperature exposure and gets loosened which can lead to leakages of liquid sodium to the air environment with the consequent fire. This is a serious safety issue.
- On completion of creep test, the drainage of liquid metal trapped inside the bottom bellow is difficult to carry out.
- In the event of failure of the draw head mechanism for beam leveling, excessive pulling of the bellow may rupture it, leading to leakage of liquid sodium.

### *2.3. Special features required for carrying out creep test in flowing liquid sodium*

The following design features of the creep testing chamber are required to carry out creep test in flowing liquid medium:

- Arrangement to maintain constant flow rate of liquid sodium across the creep specimen.
- Bellows should not carry the load of flowing liquid sodium.
- Use of less number of bellows to decrease the stiffness of the bellow system so that the creep specimen experiences the desired load.