Tender Notification for Procurement of a "Mechanical Tester Capable of Performing Thermo-Mechanical Fatigue, Creep and Creep-Fatigue Interaction Tests" at IISc

(Last Date of Submission of Tenders: 26th March 2019)

Dear Sir/Madam,

In order to accomplish the goals of a Government funded project, purchase of a mechanical tester capable of performing thermo-mechanical fatigue (TMF), creep and creep-fatigue interaction (CFI) tests is planned. The machine will be used for testing of hollow and solid specimens of nickel-based superalloys (main focus), stainless steels, ferritic steels and their welds at temperatures ranging from 200 to 1200 °C (furnace temperature). As per the specifications of the project, the major focus will be on the TMF capabilities of such an equipment. Below, firstly details of the different types of tests are given, followed by the detailed technical specifications of an ideal machine.

DETAILS OF TESTS:

a. Thermo-Mechanical Fatigue (TMF) Testing

The machine shall be capable of applying controlled thermal and mechanical loading waveforms between predefined minimum and maximum temperatures and strain amplitudes, as per the standard **ASTM E2368-10**. The temperature-strain phase angles shall be variable between 0 and 180°. The system must operate using triangular, trapezoidal and other complex mechanical loading waveforms under strain or load control.

<u>Specification of tests</u>

i. Tests will be conducted under mechanical strain control mode, using total axial strain amplitudes in the range, ± 0.2 to ± 2%, where mechanical strain = total strain – thermal strain.

ii. For tests involving hold times, strain dwell (generally at the peak tensile/compressive mechanical strain) periods from 1 min to 1 h will be used.

iii. R-ratios ($\sigma_{min}/\sigma_{max}$) shall be variable between +1 and -1.

iv. Heating and cooling rates of the test specimen (gauge length and gauge diameter of 25 mm and 11.43 mm respectively, see Fig. 1) shall be variable between 1 and 10°C/s.

v. The grips shall have adequate heat dissipation capacity to affect a natural cooling of up to 5 °C/s, in the absence of any forced air cooling. For tests involving higher heating/cooling rates, provision for forced air cooling shall exist. Grips shall have suitable provision to allow the airflow through the internal specimen porting to enable higher rates of thermal cycling. Provision to have a controlled airflow to achieve the desired temperature variation shall exist.

b. Creep Testing

The machine shall also be able to perform creep test as per **ASTM E139−11** (Reapproved 2018) over extended periods of time. Round sample, similar to that shown in Fig. 1, having a gauge length of 25 mm will be tested.

Specification of tests

i. Tests will be conducted under both constant load and constant true stress modes.
ii. All attached electronics and software should be stable at least for 30 days, thereby allowing uninterrupted, unsupervised testing for a minimum of 30 days.
iii. Tests at constant temperature ranging from 200 to 1000 ^{o}C should be performed, with less than ±1 ^{o}C variation in sample temperature along the sample length and over period of the test.
iv. Machine shall allow performing load jump (both increasing and decreasing) tests.
v. Machine shall also allow performing stress relaxation study.
vi. Optional: Creep crack growth tests lasting up to 5,000 h shall be performed.

c. Creep-Fatigue Interaction Testing

In addition to the normal TMF, the system will also be used for conducting isothermal strain and load controlled (low cycle) fatigue tests as per the standard **ASTM E606**.

Specification of tests

i. The machine should allow performing tests with long hold/ dwell times with intermittent fatigue load applications.
ii. Tests at constant temperature ranging from 200 to 1000 ^{o}C should be performed

TECHNICAL SPECIFICATIONS FOR MACHINE:

1. Load frame specifications

- The load frame shall be of a rigid, two-column construction with a fixed lower level platen and a variable upper cross head.
- The unit shall be free standing for installation on a standard concrete floor without requiring any special foundations.
- It shall be possible to position and lock the upper cross head using hydraulic/ electric means.
- The actuator shall be equipped with a stroke measurement transducer.
- The load frame shall meet the general specifications as mentioned below:

Frame capacity:	±250 kN
Load frame stiffness:	450 kN/mm or more at 1m daylight; In addition, high lateral stiffness should be there to ensure performing fatigue tests with substantial

compressive strains without buckling or additional bending strains.

Vertical daylight:	150 – 1200 mm or better
Horizontal daylight:	>600 mm
Actuator:	±100 kN high precision direct drive linear servo-electric actuator capable of displacement rates between 1 μm/h and 250 mm/minute (or better), with a travel of ±75 mm (or more). Maximum dynamic performance should be ± 1.0 mm at 1.0 Hz or better. The actuator shall have in-built anti-rotation mechanism to prevent any angular rotation throughout its stroke. The servo-motor should be directly coupled with precision ground ball screw assembly to provide high reliability, precision control and zero backlash. The actuator should be rated for creep and creep-fatigue tests also. A high-resolution displacement transducer should measure the stroke of the actuator.

Note: Details of technology (or technologies), which is used for providing high precision and reliability of actuator movement should be provided. The committee will evaluate the functioning (and abilities) of such mechanisms against the promises made. The committee will make its decision based on the information provided at the time of submission of the tender documents.

2. *Alignment*

- Alignment should meet ASTM **E1012**.
- The specifications below are mentioned for the sample shown in Fig. 1; however, a solid one made of high strength steel (that can accommodate stresses of 400 MPa or more). The specimen for alignment, to be provided by the vendor, should be bonded with minimum 12 strain gauges.
- Alignment adjustment and monitoring shall be provided via an alignment fixture, complete with all necessary hardware and software tools including a strain gauged specimen.
- Angularity and concentricity adjustment shall be possible with the load string in the pre-loaded condition.
- Load frame alignment accuracy shall be better than 0.5 mm/m.
- Bending alignment shall be verified by a strain gauged test piece to be less than 5% at 0.4% strain.

3. *Specimen grips and loading bars*

- TMF: Water-cooled and self-aligning hydraulic collet grips rated to ±100 kN with zero backlash, incorporating suitable collets for gripping the specimen similar to that shown in Fig. 1 shall be provided.
- Creep: Appropriate push / pull rods with end connectors (to be piggy backed to the aforementioned water-cooled hydraulic grips) meeting the drawing shown in Fig. 1 should be provided.
- Creep, LCF, Creep-Fatigue Tests: Push/ pull rods shall be of high temperature superalloy construction, capable of being used up to a temperature of 1000 °C or more. They should be capable of performing LCF tests in compression-tension as well as tension-tension conditions using both button head and threaded specimens. Proper adapters should be provided.
- Cooling of grips should be adequate so that a sample heated to 1000 ºC can be attached with it.
- The water-cooled grips shall serve as a primary mechanism for specimen cooling during the TMF cycle.
- The grips shall be mounted onto the load frame and actuator in a manner that allows for easy mounting and unclamping of the test piece with suitable provision for adjustment of the angular and concentric misalignments.

4. *Load cell*

a.	Capacity:	±100 kN
b.	Linearity error:	<±0.08% of reading
c.	Repeatability:	Better than ±0.25% of reading
d.	Hysteresis:	<±0.1% of full scale
e.	Zero error:	<±0.1% of load cell rating upon load removal
f.	Sensitivity:	1.6 to 2.4 mV/V at dynamic rating
g.	Fatigue life:	$>10^9$ full stress reversed cycles at load cell capacity
h.	Overload capability:	150% static rating without permanent zero shift, 100% fatigue rating
i.	Compensated temperature range:	+15 to +50°C
j.	Temperature effect on zero:	<±0.002% of load cell rating per °C
k.	Temperature effect on sensitivity:	<±0.002% of load cell rating per °C
j.	Resolution:	0.02% of FSR

5. *Heating system and temperature measurement*

- The heating unit should be able to produce an accurate and stable temperature over a temperature range of 200 to 1200°C (furnace temperature).
- The following 2 independent heating units shall be provided:
  - TMF Testing: Heating shall be provided by a high frequency (80 to 400 kHz) microprocessor-controlled induction heater, interfaced with a closed loop temperature controller. Temperature measurement and control shall be through K-type thermocouple wires that shall be welded with the specimen surface at three different locations within the gauge section. One of these thermocouples shall serve as the feedback sensor for closed loop temperature control. The RF power supply unit shall be equipped with suitable RF filters to ensure that there is no RF interference and noise that could adversely affect the performance of other sensors/transducers. The induction coils shall be manufactured from high quality HCOF copper and the system shall have suitable power rating (typically 5 – 6 kW) to achieve the temperature and heating/cooling rates mentioned above, in both non-magnetic and ferromagnetic test specimens. Supply shall include the necessary chiller unit. Dynamic temperature gradients along the 25 mm gauge length shall be maintained at ±1% of the maximum temperature (T_{max}) of TMF cycling or ±3°C (whichever is greater) by suitable induction coil arrangement. The coil shall be adjustable in the vertical and radial directions for minimizing the gradients whenever necessary.
  - Creep and Creep-Fatigue Testing: Heating shall be provided by a 3-zone furnace, with an independent micro-processor-based Eurotherm temperature controller for each zone. Each zone should be heated differently, whereas a K-type thermo-couple attached to the center of the sample should provide closed-loop feedback to maintain the temperature – for this, another independent, master Eurotherm temperature controller should be provided. Provision of placing additional K-type thermocouples (i.e., in total at least 2) onto the sample should be provided. Temperature stability should be better than ±1 ºC between test temperatures of 200 and 1200 ºC (sample temperature). The height of the hot zone should be more than 300 mm, with more than 150 mm of it being uniform temperature zone. The furnace should have alumina and zirconia fiber insulation system for minimizing heat loss and prolonging the life of furnace. There should be a viewing port made of quartz or some other appropriate materials. The dimensions viewing port should be 30 mm × 10 mm (or equivalent). Provisions (e.g., with fully center split design) shall be provided to swing / slide the furnace out of the test zone, if the furnace is not needed. Furnace design should allow the operator to work from the front of the furnace at all times. The design should allow proper furnace alignment, thereby restricting the temperature gradient.

- Suitable display devices shall be supplied for independent monitoring of sample temperature(s).
- Provision shall exist to acquire and record the sample temperature(s) in the test results file at pre-defined interval.
- Safety interlock: The grip water cooling circuit should have flow switches that are integrated with the temperature controller. The switches should shut down the furnace to protect equipment and specimens in the vent of a water supply failure.

6. *Spot welding unit for thermocouple (Optional)*
   - Offer shall include a spot-welding unit for welding the thermocouples onto the specimen.

7. *Extensometer*
   - The total strain shall be continuously monitored via a minimum resonance, side-contacting axial extensometry with a low contact pressure.
   - The extensometer transducer shall be provided with suitable mounting unit for fixing the extensometer onto the specimen and a cooling device for use in the above-mentioned temperature range.
   - Supply shall include 4 pairs of the ceramic rods as spares.
   - Calibration/verification of the extensometer shall be performed using accredited calibration jig and a certificate for the same shall be provided.
   - Either one extensometer with proper fixtures for both TMF and creep (i.e., high temperature furnace) or two different extensometers, with each being dedicated to one type of test, shall be provided.
   - Other specifications shall be as follows:

a.	Contact pressure on specimen:	300 grams per rod
b.	Gauge length:	25 mm
c.	Travel:	+2.5, -1.25 mm
d.	Rod type:	Alumina chisel end
e.	Max. frequency:	2 Hz.
f.	Temperature range:	Ambient to +200°C (body); Ambient to 1200°C (specimen)
g.	Temperature coefficient:	0.01% full scale output (FSO)/°C
h.	Repeatability:	±0.1% FSO
i.	Typical hysteresis:	0.07%
j.	Resolution:	1 µm or better

8. *Control electronics*

Appropriate control electronics should be provided to perform the specified tests and to meet the technical requirements mentioned above. In addition, a few unique features of the control electronics are highlighted below:

Control electronics:	Full digital control with a 32-bit resolution
Control loop parameters:	Proportional, integral and derivative parameters shall be automatically and continually updated for each control mode to maintain optimum control throughout each test.
Transducer ranges:	Both real-time automatic and manual ranging of signals shall be available on stroke, load and strain transducers.
Fault diagnostics:	The control console shall be capable of performing diagnostic tests during power up and report and define any fault found.
Power failure:	The electronics should be robust against sudden power failures. If such a provision cannot be provided, then a UPS, with at least a 30 minutes long power backup for the important component of the machine, should also be included in the quote.

9. *Software*

The software package shall be capable of performing TMF (including complex cycling of both temperature and mechanical loading of the specimen), creep and creep-fatigue tests. In addition, a few unique features of the software are highlighted below.

- *Limit sensing:* Limit detection on stroke, load, mechanical strain, total strain and temperature shall be incorporated along with definition of limit action (such as test stop/shift in control mode).
- *Break criterion:* The software shall have a provision for test termination upon drop in the peak stress from the saturated/stabilised value. Provision to define /update the value on-line, even as a test is in progress would be desirable.
- A computer with appropriate hardware and software should be provided.

10. *Data-logging requirements*

- Real-time, continuous monitoring of the output parameters is required with linear/logarithmic/user-defined data-logging features.
- Data collection sources shall be selected from stroke, load, stress, total strain, mechanical strain, thermal strain (the correction profile), control and monitor temperatures, time, cycle number, demand and control error, at a continuous synchronous data acquisition rate of 5 kHz or more per sensor on all channels.

- Software shall be capable of acquiring and storing stress-strain hysteresis loops at user-defined sampling rates. A hysteresis loop shall contain a minimum of 500 data points that would be stored in a tabular format. Provision shall also exist for capturing additional hysteresis loops even as a test is in progress.
- Provision shall exist for dynamic transfer of raw data to Microsoft Excel for analysis.
- For TMF and creep-fatigue tests, there shall be provision for continuous and peak-valley data display in user-defined channels. Real-time graphical display of the stress-strain hysteresis loops and the cyclic stress response plots shall be incorporated.
- Continuous graphical display of any user-defined channels (such as temperature (control/feedback), strain (thermal/mechanical/total), load, stroke etc.) against time shall be possible throughout the test.
- Test interruption facility shall be incorporated, allowing the operator to pause a test on completion of a specific number of cycles (in case of TMF and creep-fatigue tests), time or strain (in case of creep test). The specimen shall be ramped to zero load and temperature reduced to ambient, while maintaining zero load.
- Data should be saved continuously on the hard-disk of computer and there should be a fail-proof system of retrieving the data, without any loss, in case of sudden power failure.

11. Specific software requirements for TMF

TMF testing, including a pre-test automatic thermal strain verification procedure to determine the thermal strain response of the specimen shall be performed in four stages:

a.	Initial heat-up and temperature stabilization	
b.	Thermal strain measurement:	Thermal cycling of the specimen under zero load using a pre-defined temperature waveform to calculate the strain correction profile (averaged over several thermal cycles, if desired).
c.	Thermal strain verification:	Re-run of the above temperature profile with the specimen in strain control using the calculated thermal strain value. Herein the software shall supply a mechanical strain that equals the thermal strain measured in the previous step. Load values would be monitored to detect any deviation from zero load.
d.	Main test:	Cycling of the specimen under user-defined thermal-mechanical strain waveforms.

14. *Installation, commissioning and training*

- The detailed site preparation, including power requirement, should be shared with IISc at least 2 months before the shipment of the machine.
- The machine shall be delivered, installed and commissioned at Department of Materials Engineering, Indian Institute of Science, Bangalore (India), where the users shall be trained for a total of one week (can be spilt in two sessions) after installation, inspection and commissioning.
- During the inspection and commissioning phases, the supplier shall demonstrate all the functions of the system in accordance with the specifications, through 2 complete TMF tests on each specimen (at least 5 specimen) on user-supplied test specimens.
- The manuals covering the operating instructions, along with the software shall be supplied at the time of delivery of the equipment.

15. *After-sales service*

- The supplier shall be able to provide a single source service facility for the above equipment, including a calibration and software help desk.
- Company must have a service and training center in India
- Company must guarantee 10 years of continued support and service even after the discontinuation of the supplied model.
- Consumables and their cost should be mentioned clearly and the cost of same should be fixed for a period of 3 years
- Once installed, the equipment shall be guaranteed for a period of one year.
- Optional: After the warranty period elapses, the supplier must offer annual service contract for 3 years to maintain and calibrate the whole testing system. Calibration of load cells and extensometers must also form part of such a contract. Cost of the maintenance contract shall be quoted separately in the offer.

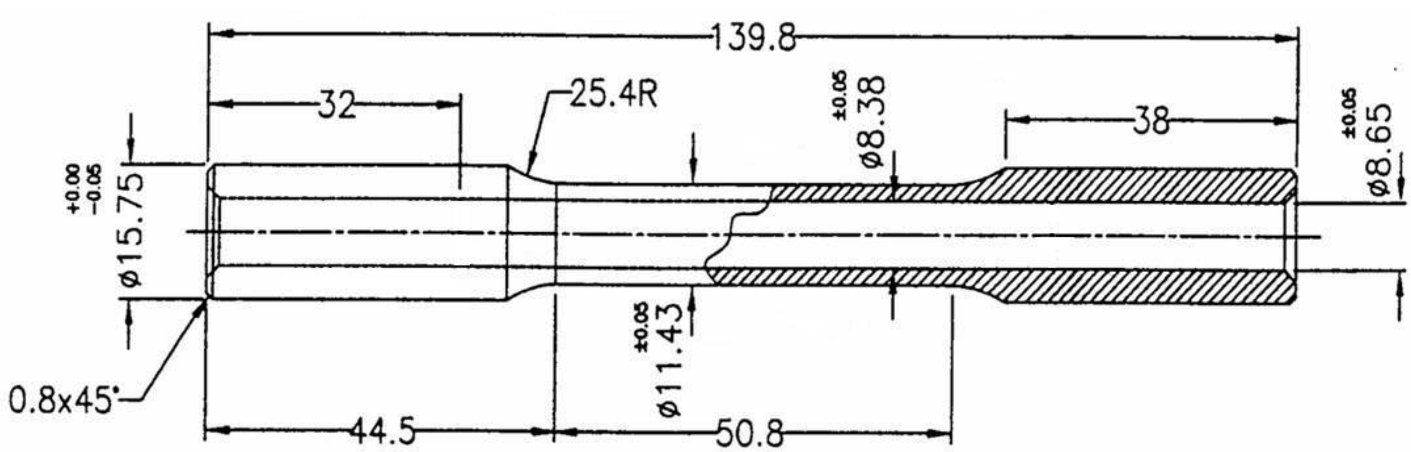

Figure 1: TMF specimen geometry (ferritic steel)

TERMS AND CONDITIONS

1. Two-bid system (separate technical and financial bids) in sealed tenders.
2. The technical bid must clearly specify the prescribed technical specifications without including the prices. Please provide in detail the specifications under each subhead and bullet point. Unique characteristics may be highlighted.
3. Vendors who include price information in the technical bids will be automatically disqualified.
4. At least 3 independent reference letters from India should be provided. IISc may contact more users for obtaining independent references. The committee will have right to reject a bid based on reference letters.
5. Technical bids will be opened first. IISc may seek clarifications after opening of technical bids and may ask vendors to perform some example experiments on the samples given by IISc to demonstrate the promised technical specifications. Vendors may be required to give presentations.
6. There are several items that require detailed information to be provided by the supplier. If information is not provided against any of these items, this will disqualify the supplier.
7. After technical evaluation by a committee, vendors may be asked to re-quote in a specific format to facilitate comparison of prices.
8. Price bids of only technically qualified vendors will be considered.
9. The price bids must offer CIF Bangalore prices.
10. Prices to be quoted separately for baseline system and options. Prices should be quoted in adequate detail with relation to packing details to cover insurance compensation in case of damage to any specific modules
11. Indicate separately price of spares listed above in terms of unit cost. The price of these spares will be included in the price comparison. Any additional spares recommended by the company will be considered for ordering but not included in the comparison. The buyer reserves the right to make the final decision on ordered spares.
12. IISc also reserves the right to cancel the tender at any time without assigning any reason whatsoever.
13. Indicate delivery period
14. Order will be placed on lowest bid from technically qualified vendor
15. The tender documents can be sent at the following address:

    The Chairman
    Interdisciplinary Center for Energy Research (ICER)
    Indian Institute of Science, Bangalore 560012
    Karnataka (INDIA)
    Attn: Professor Praveen Kumar