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N94-22620

A High Temperature Fatigue Life Prediction Computer Code Based on the Total Strain Version of Strainrange Partitioning (SRP)

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A recently developed high-temperature fatigue life prediction computer code is presented and an example of its usage given. The code discussed is based on the Total Strain version of Strainrange Partitioning (TS-SRP). Included in this code are procedures for characterizing the creep-fatigue durability behavior of an alloy according to TS-SRP guidelines and predicting cyclic life for complex cycle types for both isothermal and thermomechanical conditions. A reasonably extensive materials properties database is included with the code.

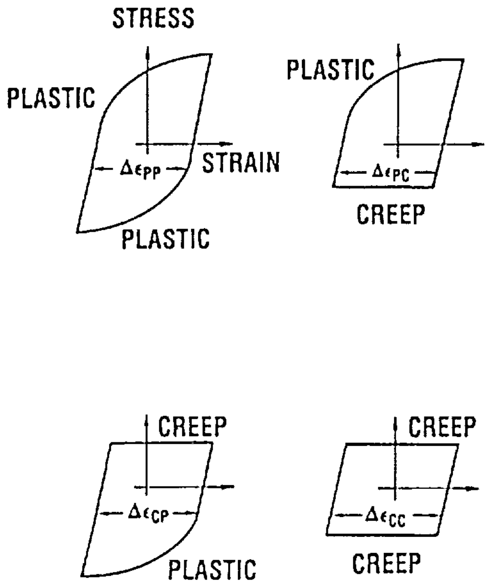
OVERVIEW

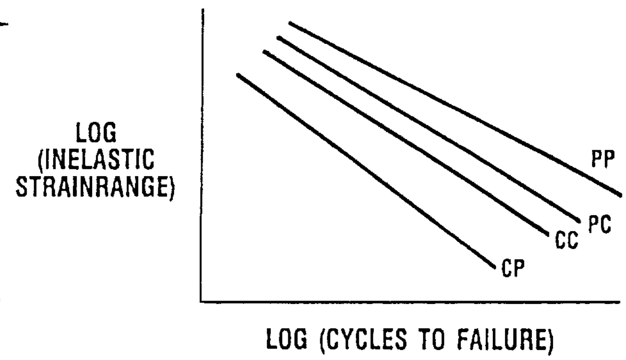
While several computer codes have been developed and are in use for the treatment of fatigue of structural metals and alloys that operate at sub-creep temperatures, the treatment of high temperature fatigue has not shared this level of development and availability for a number of reasons. The number of high temperature applications is certainly far fewer in number and the level of development of the life prediction models is not as great. This is due to the additional complexities of material behavior above the sub-creep range, since additional damage and deformation mechanisms may become operative. The need to adequately represent material deformation behavior in order that reasonable life prediction calculations may be performed has also proved to be a significant impediment in enabling the general use of high temperature durability prediction methods as well.

- **SRP & TS-SRP Life Prediction Approaches**
- **Code Modules Supporting TS-SRP**
- **Overall Code Organization**
- **Summary**

STRAINRANGE PARTITIONING

This paper describes a suite of computer programs that collectively implement the total strain range version of Strainrange Partitioning. Strainrange Partitioning, or SRP, was formulated on an inelastic strainrange basis, wherein the cyclic life is a function of the type and magnitude of the inelastic strainrange at a specific temperature. This approach has worked well in the high-strain, short life regime for which the inelastic strains are large enough to be determined accurately by analytical or experimental means.





$$\Delta\epsilon_{pp} = A_1 (N_{pp})^{a_1}$$

$$\Delta\epsilon_{cp} = A_2 (N_{cp})^{a_2}$$

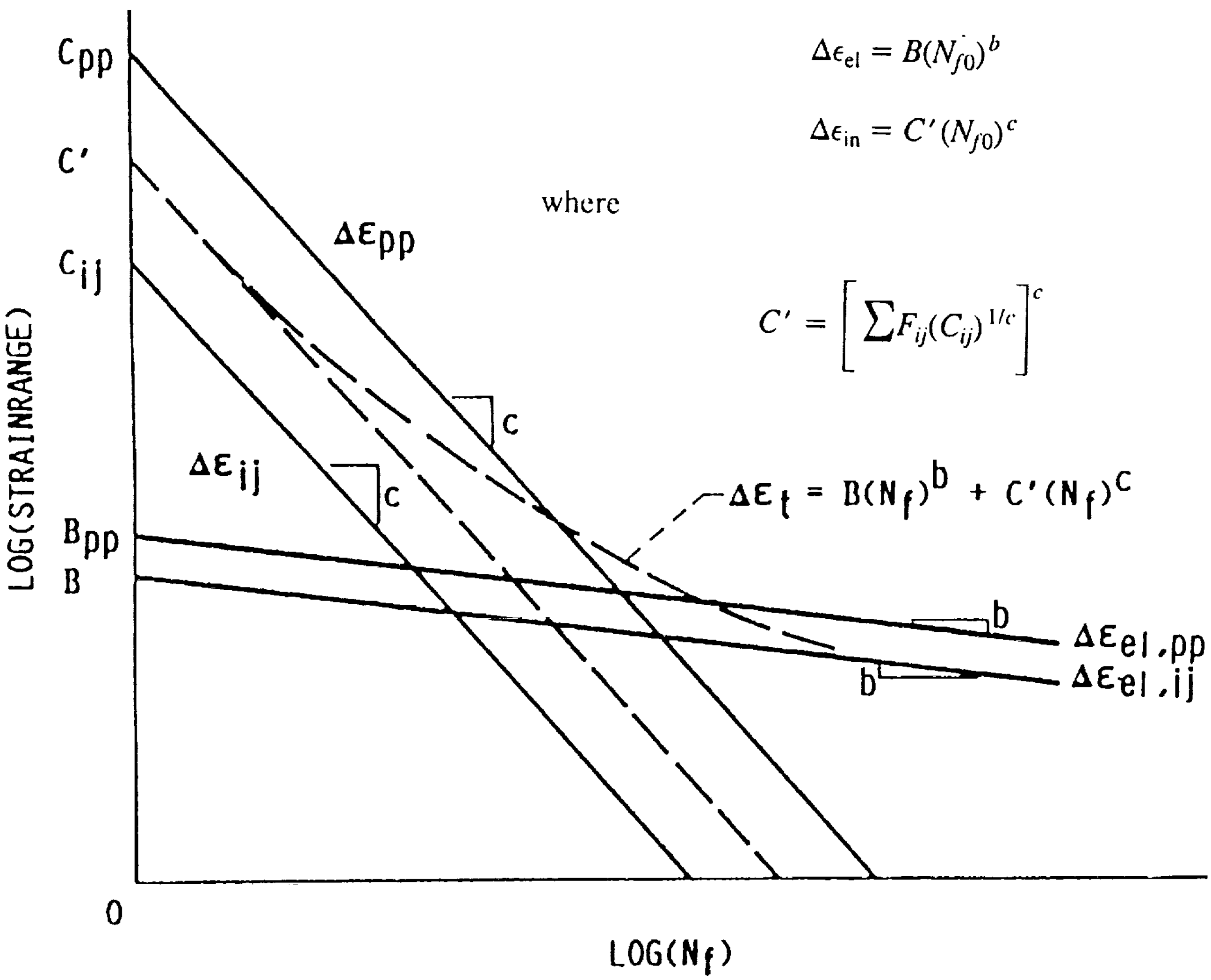
$$\Delta\epsilon_{pc} = A_3 (N_{pc})^{a_3}$$

$$\Delta\epsilon_{cc} = A_4 (N_{cc})^{a_4}$$

$$\frac{1}{N_f} = \frac{F_{pp}}{N_{pp}} + \frac{F_{cp}}{N_{cp}} + \frac{F_{pc}}{N_{pc}} + \frac{F_{cc}}{N_{cc}}$$

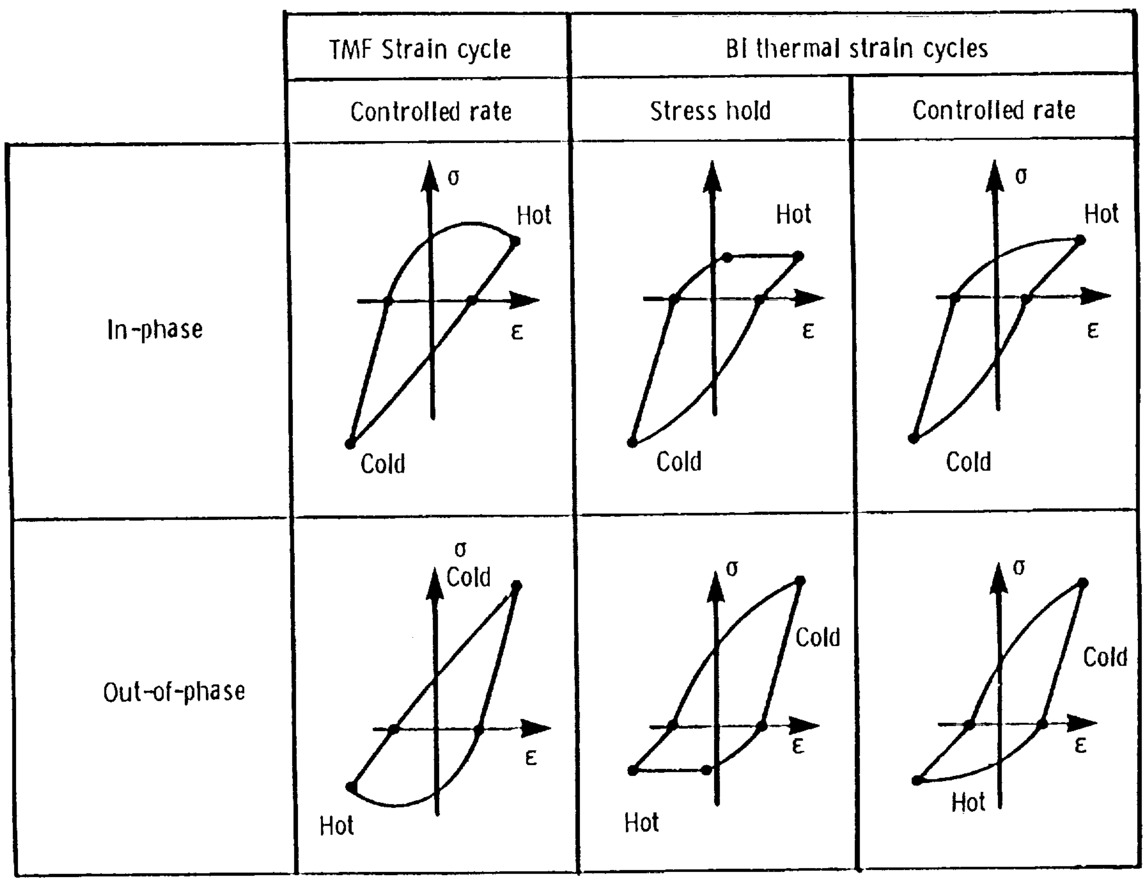
TS-SRP BASIS

In order to extend the SRP approach to address the lower-strainrange, longer-life regime, where the inelastic strains are small and difficult to determine, it was necessary to consider the total strainrange rather than just the inelastic strainrange. The method subsequently developed was termed TS-SRP, for the total strain version of Strainrange Partitioning. The computer program suite described in this paper has been developed to support the characterization of engineering alloys and prediction of cyclic life in the high temperature, long-life regime for isothermal and nonisothermal fatigue conditions using the TS-SRP life prediction methodology.



BITHERMAL APPROXIMATION FOR THERMOMECHANICAL FATIGUE

The application of the SRP approach to Thermomechanical Fatigue (TMF) is done through the use of the bithermal fatigue approximation to TMF. The bithermal approach has been utilized in extending the total strain version of SRP to encompass TMF, but addresses the uniform loading case. In the bithermal approach, the thermomechanical cycle (in-phase or out-of-phase) is approximated by a cycle in which the tensile portion of the loading is conducted isothermally at one temperature, while the compressive portion of the loading is performed isothermally at another temperature. The advantages of this approach include: 1) the testing requirements of bithermal fatigue are much simpler than those of TMF, 2) isothermal behavior may be related to bithermal behavior provided no new mechanisms of deformation and damage are introduced by the change of temperature, and 3) the micromechanisms of deformation and damage in the bithermal cycle should be easier to interpret and relate to isothermal behavior due to the increased contrast offered by the discrete nature of the bithermal cycle.

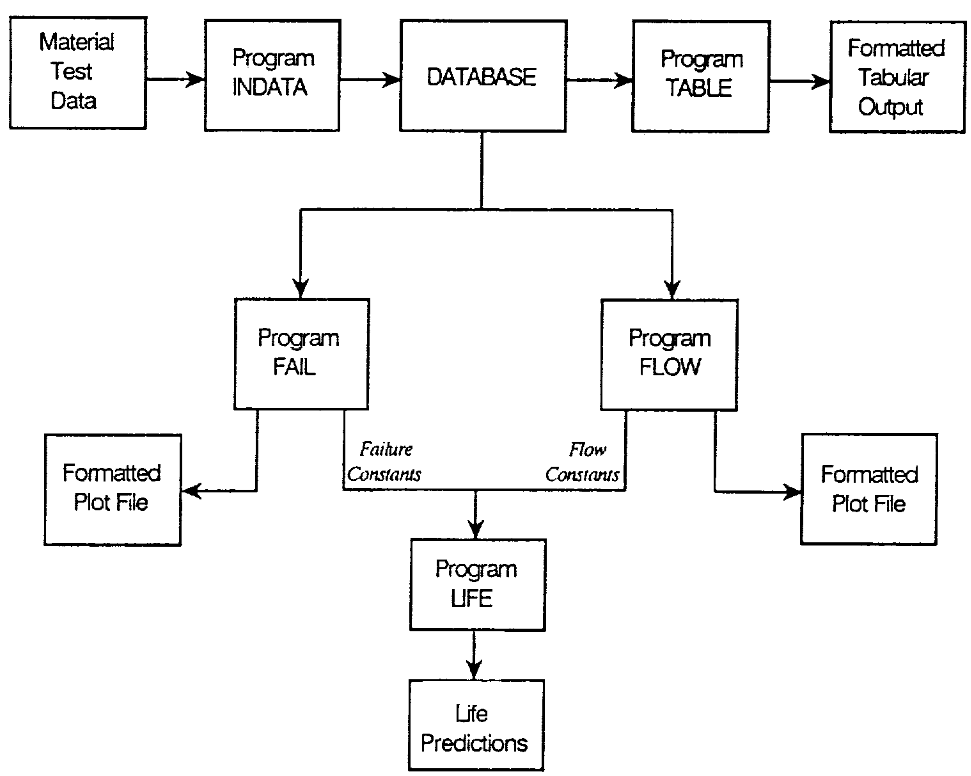


TS-SRP PROGRAM SUITE ORGANIZATION

A total of five computer programs comprise the suite that has been developed for TS-SRP; their organization is as shown.

Two codes are used to manage the input and display of material properties data: INDATA and TABLE. INDATA is used to input summary data obtained from creep-fatigue experiments into a database for use by the flow and failure analysis programs. Typically, these data consist of the alloy designation and data source, and the cyclic parameters that described the material deformation and failure behavior. The programs FAIL and FLOW will be discussed in the next two figures. The program LIFE is used to predict cyclic life using the information generated by the programs FAIL and FLOW.

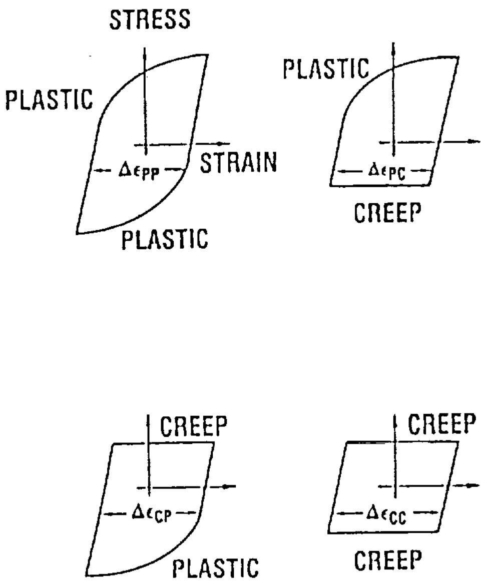
This program suite has been implemented on an IBM-AT running MS-DOS v. 3.10, and equipped with a numeric coprocessor, hard drive and two floppy drives. The language processors used were IBM Advanced Basic v. 3.0 for the program LIFE, and Lahey FORTRAN-77, v. 4.0 for the FORTRAN programs. The programs have been written with an emphasis on portability, and other FORTRAN-77 compilers and Basic interpreters and/or compilers (compliant with IBM Advanced Basic) may be suitable for use as well. These programs, as well as the associated database of material properties are available through COSMIC, NASA's agent for software distribution. The diskettes contain source code, executable files and sample output, as well as a cyclic creep-fatigue database for many materials (see figure that precedes Summary page). A user's manual has been developed for this program suite and is included with the software. This manual is also available as a NASA report.



PROGRAM: FAIL

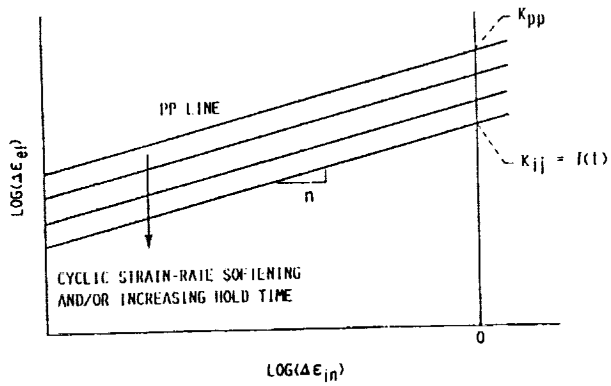
The program FAIL is used to determine the four generic SRP inelastic strainrange-life relations and the time-independent elastic strainrange-life relation for the PP cycle type. All constants in the life equations are determined through regression analysis of the appropriate data (that have presumably been entered using INDATA). The user also has the option of determining the time-dependent elastic strainrange-life relations for cycles (e.g., PC, CP and CC) with time-dependent inelastic strains. This option is typically used when the hold time per cycle is a controlled variable.

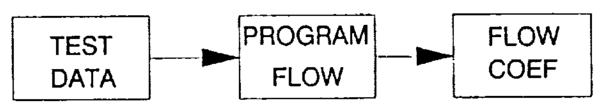
FAIL first determines the inelastic and elastic strainrange PP life relations and then proceeds to determine, in order, the PC, CP and CC strain-life relations, provided sufficiently adequate data have been previously input. As an option, the user may elect to correct data to account for mean stress effects. Upon completion of FAIL, two files are produced: the first contains the regressed constants for the SRP life relations together with the data used to make this determination.

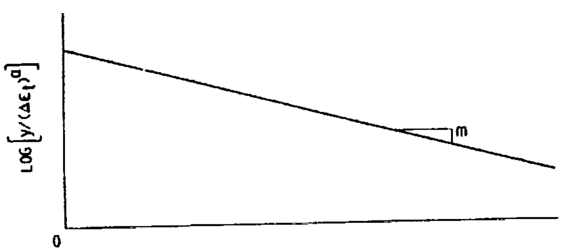


PROGRAM: FLOW

The program FLOW is used to obtain the time and waveshape dependent flow variables used to determine the constants in the flow equations, and the stress and strain values required for the mean stress correction equation. The various constants required may be determined in a number of manners, relying on a multiple regression analysis approach. Upon completion of FAIL, two files are produced: the first contains the regressed constant for the strain hardening coefficient together with the data used to make this determination, while the second contains these data in a format that is well suited for use with commercially available plotting software.







K_{ij} versus hold time
F_{ij} versus hold time
To determine B and C'

$\Delta\epsilon_{el}$ versus hold time
$\Delta\sigma$ versus hold time
σ_c versus hold time
σ_t versus hold time
To determine mean stress correction

FORMATTED OUTPUT EXAMPLE

Once entered and verified, the data may then be printed using the program TABLE, a utility designed to provide cleanly formatted summaries of the input dataset. The figure is a sample of this output for the material AF2-1DA. Of course, the resulting database is now accessible for use in performing durability analyses using other programs in the suite.

DATE: 03/28/91

CREEP-FATIGUE DATA

LABORATORY: NASA
MATERIAL: AF2-1DA

RATE DATA & STRESSES

			RATE DATA(HALF-LIFE VALUES)					STRESSES(HALF-LIFE VALUES)					
			FREQ	STRAIN-RATE-%/SEC		HOLD TIME-SEC		TEN	COMP	RANGE	RELAXATION		
SPEC NO	TEST TYPE	TEMP-C TEN/COMP	HZ	TEN	COMP	TEN	COMP	MAX	MAX	MAX	TEN	COMP	
AF-11	HRSC	760/760	5.0E-01	2.4E-02	2.4E-02	0	0	1236.0	1336.0	2572.0	0.0	0.0	-0
AF-15	HRSC	760/760	5.0E-01	1.5E-02	1.5E-02	0	0	970.0	1021.0	1991.0	0.0	0.0	-0
AF-21	HRSC	760/760	5.0E-01	1.1E-02	1.1E-02	0	0	756.0	792.0	1548.0	0.0	0.0	-0
AF-6	HRSC	760/760	5.0E-01	1.0E-02	1.0E-02	0	0	767.0	780.0	1547.0	0.0	0.0	-0
AF-9	HRSC	760/760	5.0E-01	8.9E-03	8.9E-03	0	0	688.0	689.0	1377.0	0.0	0.0	-0
AF-33	HRSC	760/760	5.0E-01	8.2E-03	8.2E-03	0	0	674.0	676.0	1350.0	0.0	0.0	-0
AF-XX	HRLC	760/760	5.0E-01	8.4E-01	8.4E-01	0	0	689.5	689.5	1379.0	0.0	0.0	0
AF-10	HRLC	760/760	5.0E-01	8.2E-03	8.2E-03	0	0	607.0	605.0	1212.0	0.0	0.0	0
AF-3	HRLC	760/760	5.0E-01	6.6E-03	6.6E-03	0	0	564.0	560.0	1124.0	0.0	0.0	0.
AF-42	CCCR	760/760	1.7E-02	5.3E-04	5.3E-04	0	1470.0	965.0	699.0	1664.0	0.0	0.0	0.
AF-26	CCCR	760/760	1.4E-02	2.4E-04	2.4E-04	0	285.0	938.0	721.0	1659.0	0.0	0.0	0.
AF-34	CCCR	760/760	3.2E-02	7.0E-04	7.0E-04	0	428.0	983.0	626.0	1609.0	0.0	0.0	0.
AF-36	CCCR	760/760	5.0E-02	9.4E-04	9.4E-04	0	72.0	878.0	623.0	1501.0	0.0	0.0	0.
AF-40	CCCR	760/760	5.9E-02	8.4E-04	8.4E-04	0	327.0	856.0	347.0	1203.0	0.0	0.0	0.
AF-43	CCCR	760/760	3.6E-02	5.6E-04	5.6E-04	0	76.0	768.0	546.0	1314.0	0.0	0.0	0.
AF-47	TCCR	760/760	1.0E-01	2.9E-03	2.9E-03	577.0	0	701.0	1154.0	1855.0	0.0	0.0	-0.
AF-5	TCCR	760/760	1.0E-01	1.1E-03	1.1E-03	130.0	0	582.0	1028.0	1610.0	0.0	0.0	-0.
AF-27	TCCR	760/760	7.4E-02	1.1E-03	1.1E-03	46.0	0	440.0	865.0	1305.0	0.0	0.0	-0.
AF-25	BCCR	760/760	5.0E-02	1.5E-03	1.5E-03	744.0	2220.0	734.0	734.0	1468.0	0.0	0.0	0.
AF-41	BCCR	760/760	1.0E-01	2.2E-03	2.2E-03	212.0	569.0	665.0	674.0	1339.0	0.0	0.0	-0.
AF-28	BCCR	760/760	1.0E-01	1.4E-03	1.4E-03	42.0	67.0	605.0	512.0	1117.0	0.0	0.0	0.

HIGH-TEMPERATURE MATERIALS DATABASE FOR TS-SRP

A substantial database of high temperature material properties has also been developed for use with this software, including nickel and cobalt-base superalloys, titanium, copper, and iron-base alloys and austenitic stainless steels.

RENE 80	AMZIRC	AF2-1DA
IN-100	NARLOY Z	B1900+Hf
MAR M002	TIAL64V	INCONEL 625
NIMONIC 90	2.25Cr-1Mo	INCONEL 718
WASPALLOY	HASTELLOY X	INCONEL 738
RENE 95	HAYNES 188	304 SS
		316 SS

SUMMARY

A brief overview of the TS-SRP life prediction methodology has been presented. The suite of computer programs developed to implement this methodology has been described with sample output offered to demonstrate this software capability. The program suite presented includes a materials database that is among the largest of its type available in the literature and should prove to be an attractive feature of the program suite to potential users. This database, while of clear value to the TS-SRP programs described, is also of utility in the development of alternative high temperature life prediction approaches.

- **High Temperature Life Prediction Computer Code Based on TS-SRP**
- **Code Contains TS-SRP Constants Database for Several Materials**

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