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MATERIALS MEMO 71-111

AEROJET NUCLEAR SYSTEMS COMPANY
SACRAMENTO, CALIFORNIA

TO: T. A. Redfield 17 March 1971
FROM: H. Derow N4350:MM 71-111
SUBJECT: Studies Leading to Design Criteria for Storage Conditions HD:jat
DISTRIBUTION: H. Derow, P. P. Dessau, C. E. Dixon, W. F. Emmons, Project No. 187
ENCLOSURE: (1) List of References and Figures U. A. Pineda, K. Sato, L. Shenfil, P. P. Ventura

MASTER

I. INTRODUCTION

Reference (1)* expressed concern over the potential for stress relaxation of preloaded components during NERVA engine storage. Components of interest in the reference were defined as bolts, springs, and bearings as well as assemblies requiring interference fits. The Materials and Processes Section was requested to provide "Master Relaxation Curves" for the materials of interest. Immediate attention was given to the first two components, bolts and springs, to define the requirements for providing the requested data because stress relaxation of these is a common materials property consideration. Establishing these requirements, it was felt, could facilitate subsequent appraisal of the needs in meeting the request for data on preloaded materials in bearing assemblies and those affected in interference fit assemblies.

The operating mode of the NERVA engine imposes subzero temperatures on the bolts and springs. Space storage, due to radiation and/or solar heating, imposes the highest temperature on the parts, considered to be some value under approximately 300°F for the purpose of this investigation. The following are the NERVA bolt and spring materials:

Bolts - A-286 and Alloy 718
Compression or Belleville Springs - A-286 and BeCu

This memo describes the results of a literature and industry survey for data on relaxation properties for the materials of interest and test procedures for establishing these properties. A recommendation is made on the necessary testing to provide data meeting the project requirements.

* References are listed at the end of this memorandum.

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1002/2/71	3/31/71

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II. SUMMARY

A study was conducted to evaluate the request of the Applied Mechanics Section for stress relaxation data on NERVA materials used for bolts and springs. The following conclusions resulted from the study:

A. Stress relaxation data on A-286 and Alloy 718 bolt materials at temperatures much below 1000°F are not available.

B. Spring relaxation data for BeCu indicates the critical temperature at which significant relaxation occurs, 225-250°F, is within the regime of the maximum NERVA storage temperature and at high preload stresses could be a problem.

C. Tests must be performed if the data requested by Applied Mechanics Section is to be provided.

D. Relaxation tests on bolts must be conducted so that all effects inherent in bolted component design and assembly procedures contribute to the determined relaxation value.

Appropriate recommendations to meet project requirements are the following:

A. A-286 and Alloy 718 bolt materials, and A-286 and BeCu spring materials should be subjected to the defined relaxation tests which will provide data for "Mather" curves relating percent relaxation, preload stress and exposure temperature.

B. Bolt test procedures should be properly designed to include evaluation of the effects on relaxation of assembly techniques and component design.

C. The anticipated cost of providing the required data should be established by soliciting proposals from appropriate test organizations.

III. LITERATURE SURVEY RESULTS

A literature [Reference 2-8] and industry survey was performed to ascertain the availability of relaxation data and review testing procedures. The survey included telephone conversations with the following:

M. Manjoine, Westinghouse Research Laboratories, and Chairman, Subcommittee on Stress Relaxation, Metals Properties Council

J. Glackin, Standard Pressed Steel Laboratories

L. Mordfin, Institute for Basic Standards, National Bureau of Standards

W. Gaffigan, Allegheny Ludlum Research Laboratories

D. Pillick, Huntington Alloy Products Division, International Nickel Company

R. Davison, Associated Spring Corporation

A. Materials Data

While there appears to be a significant amount of test data available on relaxation of A-286 and Alloy 718 bolt materials at exposure temperatures above 1000°F [References 2-5], no information was found for significantly lower temperatures. The reason for this lack of data at low exposure temperatures is associated with the critical temperature for thermally-activated reactions and is discussed in detail in the section "Relaxation Phenomenon", immediately below. W. Pineda's concern, [Reference 1] was reinforced by an example of room temperature relaxation cited by M. Manjoine of Westinghouse Research Laboratories (telephone conversation); an instance of a test on 304 SS where relaxation of between 10 and 15% occurred at room temperature in 1000 hours. The conclusion resulting from evaluation of the sparse data resulting from the survey is that tests are required at the temperature of interest to NERVA, < 300°F, if the relaxation potential of bolt materials is to be determined as requested in Reference (1).

The general consensus of information collected on BeCu springs indicates the maximum use temperature for extended service without a severe reduction in allowable preload lies in the vicinity of 225 to 250°F. A typical plot of data from Reference (6), is shown in Fig. 1a. Data was found, [Reference 7], on the use of A-286 springs, see Fig. 1 b, but it does not appear directly applicable to the NERVA engine because of material condition variation. R. Davidson of Associated Spring Corporation (telephone conversation) indicated that infinite life, defined as < 5% relaxation, of a BeCu spring is obtainable at 250°F if the tensile stress is kept <<150 ksi. The NERVA storage temperature for BeCu springs appears to be sufficiently close to the apparent critical range for the material such that unless the preload is significantly below 150 ksi tests should be conducted to establish the acceptability of current NERVA design.

B. Test Methods

Among the various test methods described in the literature, two procedures warranted detailed consideration for performing tests to acquire stress relaxation data on bolt materials. These are briefly described below. In both, appropriate measurements are taken during or after elevated temperature exposure of a preloaded bolt fabricated of the material of interest. Subsequent calculations based on the test data yield relaxation as a function of time and preload.

1. Compliance Method (Reference 5)

The test assembly configuration consists of a bolt specimen preloaded in a test block. The entire assembly is exposed at the temperature of interest. A direct determination of residual load is made by measuring, as a function of time, the "lift-off" load required to reduce the transmitted load from bolt specimen to test block to zero.

2. Tensile Machine Method

A specimen is preloaded in a tensile test machine and maintained at desired temperature at constant strain. An attached strain gage provides a measure on a chart of the change in load as a function of time.

Springs fabricated from the materials of interest are compression loaded either through use of holding bolts or appropriate fixtures, Reference (8). The use of the former which is the older and simpler of the two methods requires loading of the spring to a predetermined compressed height with the bolt bearing against washers at both ends of the spring. Periodically the bolt is removed, appropriate measurements of spring length are made to determine relaxation, and the set-up is reassembled for continued exposure in the test environment.

The alternate concept of using loading fixtures allows the test, and periodic determination of relaxation, to be conducted without disassembly. There are two variations to this method. The spring can be tested in a compression test machine using a compression load cell. The machine is controlled at constant strain and a readout of load versus time can be produced automatically. Another method is through use of a creep test frame. The loading lever is removed, and load is applied through addition of weights to a pan connected directly to the test spring. Through periodic spring deflection measurements and removal of an appropriate amount of weight as the spring relaxes data are collected with which relaxation, as a function of time, is calculated.

IV. RELAXATION PHENOMENON

A. Bolts

At high temperatures, exposure of A-286 and Alloy 718 under stress causes thermally-activated creep. However, at lower temperatures, thermal-activation does not occur. Rather the mechanism is defined by M. Manjoine as microcreep or dislocation movement. It is not clear what are the critical temperatures for the NERVA bolt materials. It is presumed to be well below 1000°F based on the dearth of creep data in the literature below this temperature. It was Mr. Manjoine's opinion that the NERVA maximum space store temperature, < 300°F, is well under the critical. The non-thermally-activated mechanisms are active essentially only during the initial period of exposure and are primarily related to the redistribution of preload stresses through the section by plastic deformation. The bolts, subjected to a constant elastic strain in the application of preload, "relax" to the extent that a portion of the originally applied elastic strain is converted to plastic strain. While the total strain remains constant, it is only the elastic portion which contributes to the remaining preload on the part. The amount of stress redistribution due to plastic deformation is affected by the amount of preload and factors relating to the metallurgical condition of the material. The time apparently imposes a second order effect where the temperature is sufficiently low, based on Mr. Manjoine's statement that relaxation is essentially complete in approximately 20 hours.

The specific design of the assembly in which the bolt is ultimately used can be important as well as the materials in causing loss of preload without bolt relaxation, per se. For example, the elasticity of the system can be a consideration if bolt torquing during assembly induces a twist in the bolt shaft. Untwisting during storage can occur resulting in bolt loosening. In short bolts, the consequence may be insignificant, but the effect is accentuated as a direct function of bolt length increase. A second phenomenon is the "settling in" of mating surfaces with time after assembly to the extent that opposing surface asperities plastically deform to produce a "nested" assembly.

Thus, in ~~the~~ evaluation of bolt relaxation, it is important to consider not only the materials of interest and the effect of the exposure conditions on bolt relaxation, it is also important to establish the effect the assembly procedure as well as the as-assembled structure design.

B. Springs

It appears that low temperature spring relaxation, like low temperature bolt relaxation, is not a thermally-activated mechanism. Reference (8) describes elevated temperature spring relaxation as a phenomenon wherein the ". . . elastic strain in the outer fibers of the spring . . . is converted gradually to plastic strain or permanent set," reducing the spring height or its load carrying capacity. Further, Mr. R. Davison of Associated Spring Corporation said that approximately 80% of spring relaxation occurred within the first 20 hours after loading and the balance occurs within some fixed time period thereafter.

The wire forming a compression spring is subjected to torsional and shear stresses under load. Thus, the equivalent load carrying capacity (compared to a tension bolt) is reduced since torsional strength of steel, for example, is approximately 50% of the strength in tension. Belleville spring performance does not involve torsional loading, rather compression set or elastic-to-plastic strain conversion under stress-time-temperature influences govern relaxation.

V. RECOMMENDED TEST PROGRAM

A series of tests is proposed which will provide data with which to plot the variation of total percent relaxation versus exposure temperature at a fixed preload (in terms of strain or stress). A family of curves representing various preload levels will be generated. The plotted data will appear as in Fig. 3. The total percent relaxation can be determined conveniently since the relaxation mechanism is not thermally activated, and essentially all relaxation occurs in a finite, reasonably small, initial time period.

Individual specimens will be exposed at several temperatures under preload, $S_{\textcircled{1}}$. Relaxation will be continuously plotted as a function of time. When the curve becomes essentially asymptotic to the time axis that portion of the curve will be extrapolated back to establish the equilibrium percent total relaxation. The various data points are described in Fig. 4, and located on the appropriate $S_{\textcircled{1}}$ curve in Fig. 3.

The acceptable preload for any component is bracketed by the intersection of the lines defining the maximum allowable relaxation for the component and the exposure temperature, see Fig. 2. The data can be cross-plotted, if required, manipulating the three variables to allow extrapolation as necessary for the determination of reliability statistics.

The bolt testing concept should be one where the actual NERVA materials systems is evaluated in a test set-up simulating the NERVA design where the test configuration is assembled simulating NERVA procedures. Thus, all factors relating to the ultimate loosening of a bolt can be evaluated. A side-effect benefit will be realized in that during assembly, by torquing, of the bolted test assembly, data can be collected relating bolt torque to actual imposed bolt strain. This data would be very valuable since current methods used for calculating actual stress in bolts are accurate to within $\pm 30\%$ primarily due to many variables--friction (thread and seating), tolerance of thread engagement, tolerance on bolt and nuts, elasticity/plasticity of bolted assemblies. The specific method for conducting the relaxation test is covered thoroughly in Reference (5).

Springs should be evaluated using a compression load cell in a compression test machine which can maintain a constant predetermined strain while recording load as a function of time.

For the purpose of ultimate program planning, it is necessary to complete the following:

- A. Establish the anticipated service history of all bolts and springs defining the preload, operating life in terms of time and exposure temperature.
- B. In conjunction with Reliability and Applied Mechanics, determine the number of data points and specimen distribution to yield statistically valid curves. It is presently presumed that the variable of preload stress will range upward from a low of 85% room temperature TYS to a value slightly above the room temperature TYS.
- C. Define the program elements required to successfully complete the tests yielding valid data points.
- D. Solicit proposals from appropriate organizations to establish concrete costs for management approval.

Both the bolt and spring tests can be performed in-house through a coordinated program involving several organizations. At least one known external organization, Standard Pressed Steel Company, has the know-how, capability and inclination to perform these tests under ANSC subcontract (telephone conversation with J. Glakin). It is recommended that appropriate quotations be solicited from several sources based on our test specifications.

H. Derow
Materials Section

REFERENCES

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- (6) Spring Design and the Nickel Alloys, Bulletin of Alloy Metal Wire Company, Inc.
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- (8) High-Nickel Alloy Helical Springs, Huntington Alloy Products, Bulletin T-35

Fig. 1 - Stress to Produce Maximum 6% Relaxation After 168 hrs. at Indicated Temperature

Fig. 2 - Design Stress for A-286 Helical Springs to Produce Maximum 5% Relaxation in 168 hrs at Indicated Temperature.

Fig. 3

TYPICAL PLOT OF STRESS RELAXATION DATA

Fig. 4

TYPICAL PLOT OF TOTAL RELAXATION