RESEARCH MEMORANDUM

TENSILE PROPERTIES OF SOME SHEET MATERIALS UNDER

RAPID-HEATING CONDITIONS

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SUMMARY

Results are presented of some rapid-heating tests of some sheet materials - 7075-T6 and 2024-T3 (formerly 75S-T6 and 24S-T3, respectively) aluminum alloys, Inconel, and RS-120 titanium alloy - which are part of an investigation of a number of structural materials. The materials were tested at temperature rates from 0.2° F to 100° F per second under constant-load conditions. Yield and rupture temperatures, obtained under rapid-heating conditions, are compared with the tensile properties obtained under constant-temperature conditions for 1/2-hour exposure. Yield and rupture stresses are found to increase approximately in proportion to the logarithm of the temperature rate except where effects such as aging altered the results. Master curves are presented for the determination of yield and rupture stresses and temperatures, which are based upon the use of a temperature-rate parameter derived from the data.

INTRODUCTION

Comparatively little is known about the properties of materials under rapid-heating conditions except for fairly recent tests of various materials by some investigators at temperature rates of hundreds of degrees or more per second (for example, refs. 1 to 5). This paper will cover some results of rapid-heating tests at relatively slow temperature rates up to 100° F per second for some sheet materials - 7075-T6 and 2024-T3 aluminum alloys, Inconel, and RS-120 titanium alloy - which are part of an investigation of a number of structural materials at the Langley Laboratory. The data on the latter two materials are preliminary. Detailed results for the two aluminum alloys are given in reference 6 along with a description of the equipment and test procedures.

The rapid-heating test is a new kind of test and differs from the conventional stress-strain test. In the rapid-heating test, the load is held constant. The material is then heated at a constant temperature rate until failure occurs. In the stress-strain test, on the other hand, the temperature is held constant. After the material has been heated 1/2 hour or more at the test temperature, the load is then applied until failure takes place. Heating was accomplished in the rapid-heating tests by passing an electric current through the specimen in such a manner as to obtain a constant temperature rate. Autographic strain and temperature-time records were obtained, and yield and rupture temperatures were determined for each test.

TEST RESULTS

The strain-temperature histories for the tests of 7075-T6 aluminum alloy under rapid-heating conditions are shown in figure 1. In this figure the strains, which include the elastic, thermal, and plastic strains, are plotted against the instantaneous temperatures for each test at the different stress levels and temperature rates. These rates varied from about 0.2° F to 100° F per second - a factor of about 500. The outstanding characteristic of these tests for this material is the regular family of curves obtained at each stress level for the different temperature rates when the material becomes plastic. As long as the material remains elastic, however, a single curve is obtained at each stress level regardless of temperature rate. This single curve coincides with the calculated thermal-expansion and change-in-elastic-modulus curve for the stress level. The extensions of these calculated elastic curves are shown by the dashed lines. A thermal-expansion curve is also shown in figure 1 which was obtained for the material after it had been repeatedly heated and cooled until the same curve was obtained on both heating and cooling. Yield temperatures at which 0.2-percent plastic flow occur are indicated by the tick marks; yield temperatures increase with the temperature rate in a very consistent manner.

Figure 2 shows the logarithmic nature of this increase in yield as well as in rupture temperatures for this material. The temperature rate is given by a logarithmic scale. The curves are faired through the test points and show that both yield and rupture temperatures increase approximately in proportion to the logarithm of the temperature rate. This condition was also found to be the case for the other materials with certain specific exceptions, some of which will now be illustrated.

Figure 3 shows the effect of aging on the results for 2024-T3 aluminum alloy at 50 ksi. In this instance, all the test curves go more or less together up to yield, after which the individual curves fall into the normal pattern. Rupture temperatures follow a logarithmic relation but yield temperatures do not.

Another example of the effect of aging is shown in figure 4 for RS-120 titanium alloy at 75 ksi. In this case, the test results follow the usual pattern up to yield, but at higher temperatures the order of the curves is almost completely reversed. This behavior was not expected for this material in the stabilized annealed condition.

The last example (fig. 5) illustrates the unstable nature of the plastic flow obtained in the tests of Inconel at 28 ksi under rapid-heating conditions. Here, abrupt plastic flow occurs after intervals of more or less elastic action. In spite of this erratic behavior, yield temperatures appear to increase in regular fashion; this irregular behavior continued until near rupture. This type of action is associated with the development of Lüders' lines.

COMPARISON OF RAPID-HEATING AND STRESS-STRAIN TESTS

Although rapid-heating and stress-strain tests are two distinctly different kinds of tests, comparisons can be made between results of such tests on the basis of yield and rupture or ultimate stresses at different temperatures. The comparative results for the yield stress for the aluminum alloys are shown in figure 6. The results of the rapid-heating tests are given by the solid lines for arbitrary temperature rates from 0.2° F to 100° F per second. The dashed lines give the tensile yield stress (0.2-percent offset) for 1/2-hour exposure obtained from the stress-strain test. The main result to be noted here is that the yield stress under rapid-heating conditions may be appreciably greater or about the same at a given temperature as that obtained from the stress-strain test for 1/2-hour exposure, depending on the temperature rate and the material. For the rapid-heating tests, the effect of increase in temperature rate levels off markedly for rates above about 60° F per second.

A comparison of the rapid-heating and stress-strain results for these same materials for rupture and ultimate stress is given in figure 7. The comparisons are very similar to those found for the yield shown in figure 6. Rupture temperatures, however, run from 20° F to 60° F higher than those for yield. As in the case of yield, the increase in rupture stress becomes very small for temperature rates above 60° F to 100° F per second. Similar comparisons between rapid-heating and tensile-test results for Inconel and RS-120 titanium alloy have not been completed.

MASTER YIELD AND RUPTURE CURVES

A temperature-rate parameter was derived from the data, which was based upon the logarithmic relationship between yield and rupture temperatures and the temperature rate previously shown. With this parameter, it was found possible to reduce the results of the rapid-heating tests to a single or master curve in plots of stress against the parameter.

The correlation of the data with the master curves for the two aluminum alloys is shown in figure 8. In this parameter, T applies either to the yield or rupture temperature in $^{\circ}$F, and h is the temperature rate in $^{\circ}$F per second; the additional numbers in the numerator and denominator are temperature and temperature-rate constants, respectively. The validity of the parameter is shown by the correlation of the data with the master curves. Very good correlations were obtained in general for yield for both materials and fairly good correlation for rupture. Yield and rupture temperatures, calculated by means of the master curve and the parameter for the different stress levels, are in very close agreement with the test values, especially for the 7075-T6 aluminum alloy.

Figure 9 shows the correlation of the test points with the master curves for yield and rupture for Inconel and RS-120 titanium alloy. Good correlations were obtained for yield for Inconel and the titanium alloy except at 50 ksi for the latter where the parameter does not hold. Fairly good correlation was obtained for rupture for these materials except in the regions where aging affected the results.

CONCLUDING REMARKS

Although the rapid-heating tests for some of the materials have not been completed, the results obtained so far indicate, in general, that yield and rupture temperatures increase logarithmically with temperature rates below 100° F per second except for certain regions or stress levels for some of the materials. This increase levels off markedly for temperature rates from about 60° F to 100° F per second. Under rapid-heating conditions, materials may be stronger than indicated by conventional tensile data for 1/2-hour exposure, but the relative strength varies with the temperature rate and the material. At the present time, no theory is available for the complex transient behavior of materials under rapid-heating conditions. The use of master yield and rupture curves, however, employing a suitable temperature-rate parameter, affords a possible convenient method for determining yield and rupture stresses and temperatures for different temperature rates. In any case, adequate data are required for each material in order to establish such curves and the limitations of the parameter.

Langley Aeronautical Laboratory,
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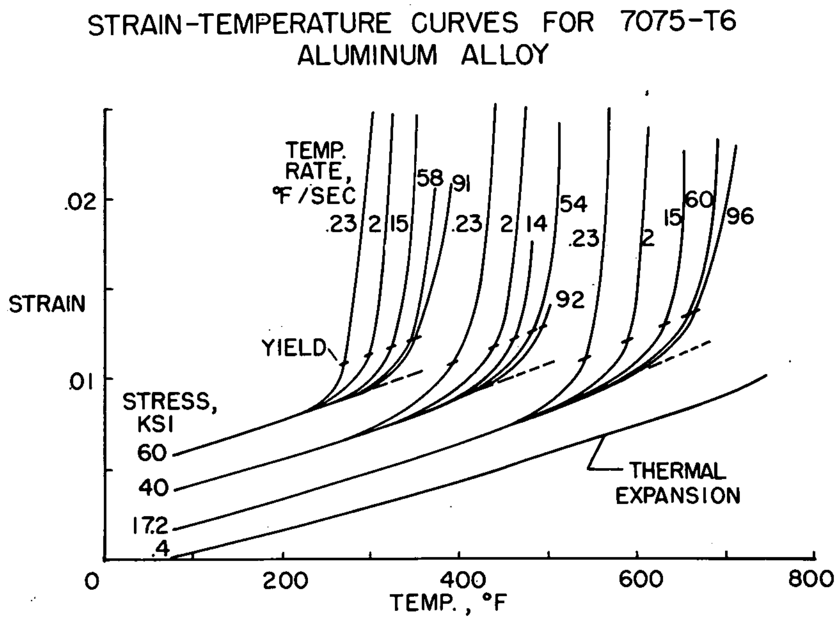

Figure 1

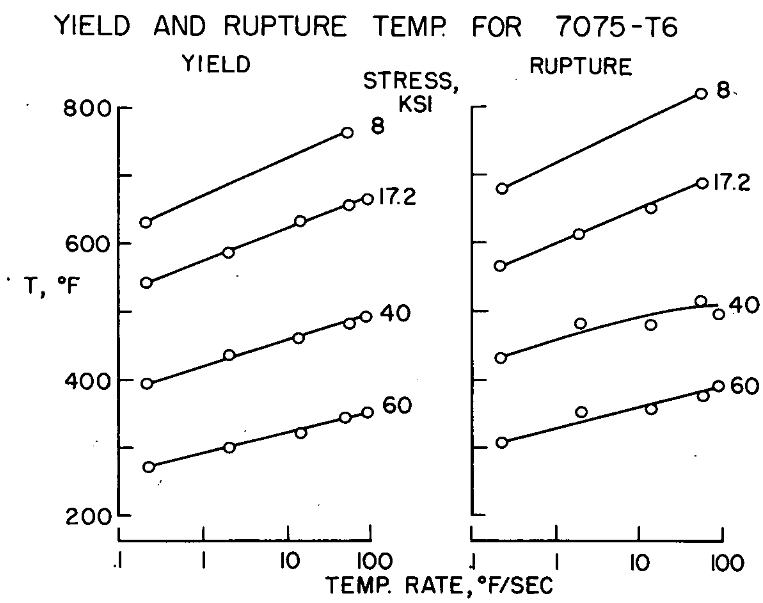

Figure 2

AGING OF 2024-T3 ALUMINUM ALLOY AT 50 KSI

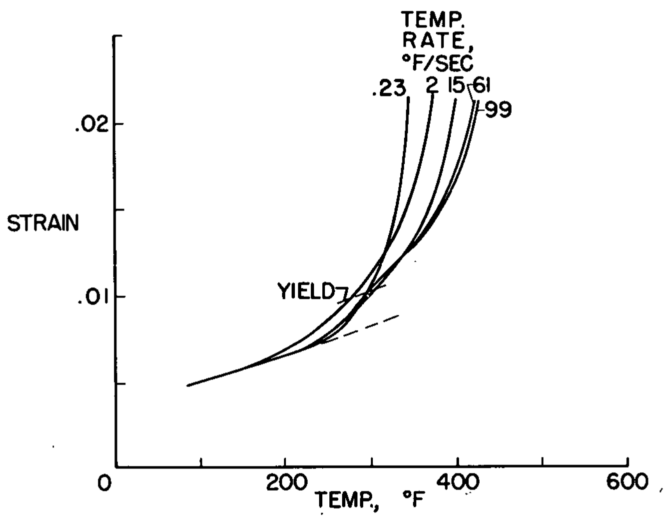

Figure 3

AGING OF RS-120 TITANIUM ALLOY AT 75 KSI

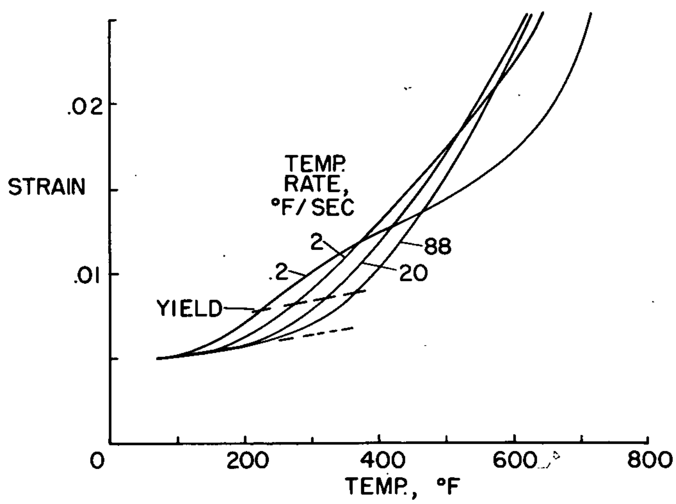

Figure 4

UNSTABLE PLASTIC FLOW OF INCONEL AT 28 KSI

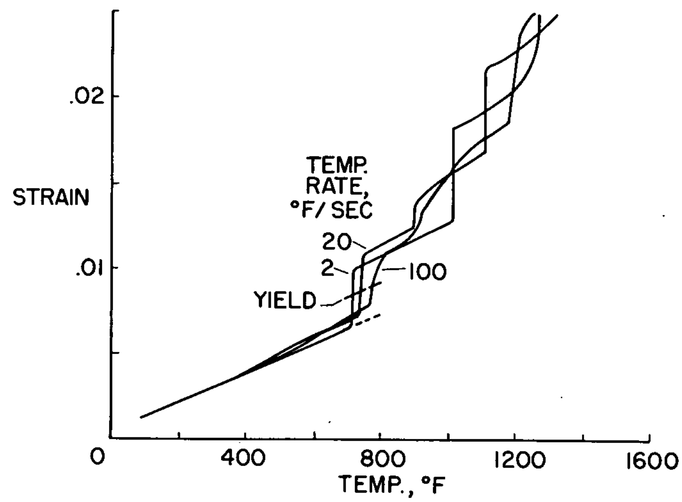

Figure 5

COMPARISON OF RAPID-HEATING AND STRESS-STRAIN RESULTS FOR YIELD

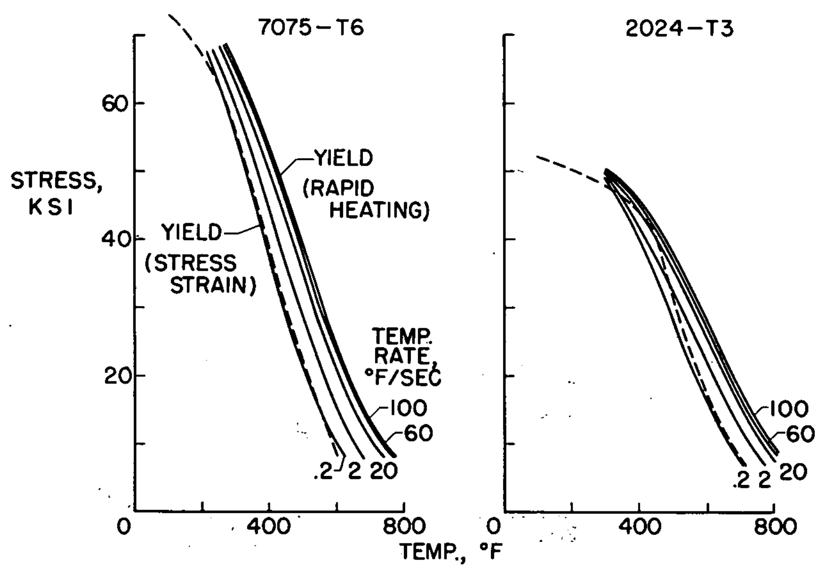

Figure 6

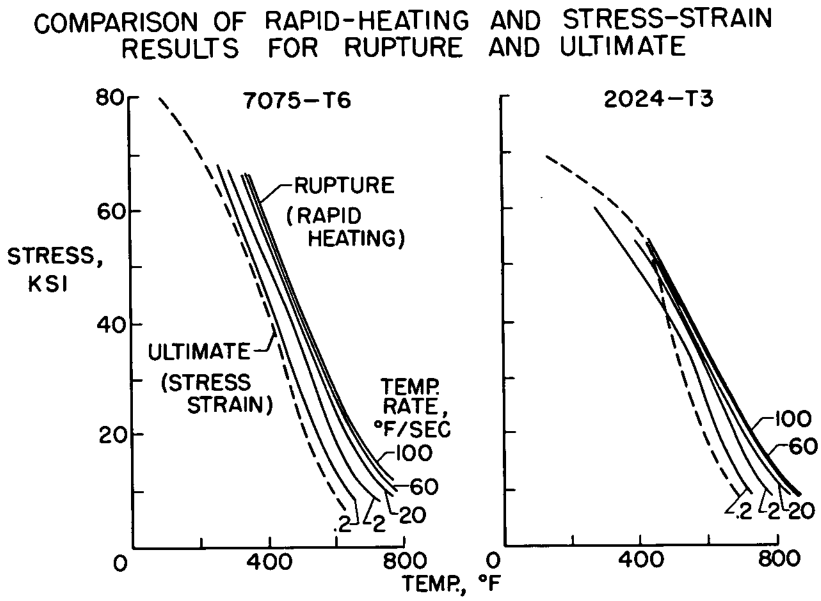

Figure 7

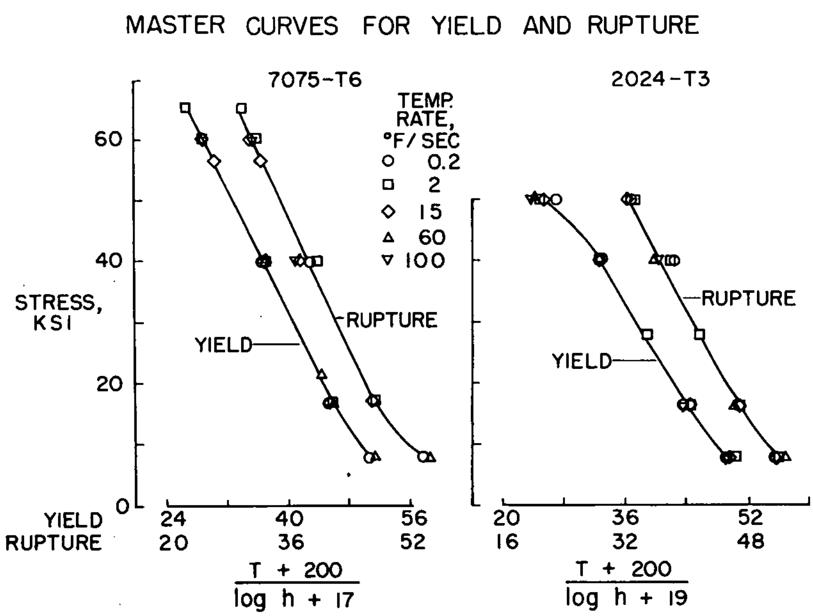

Figure 8

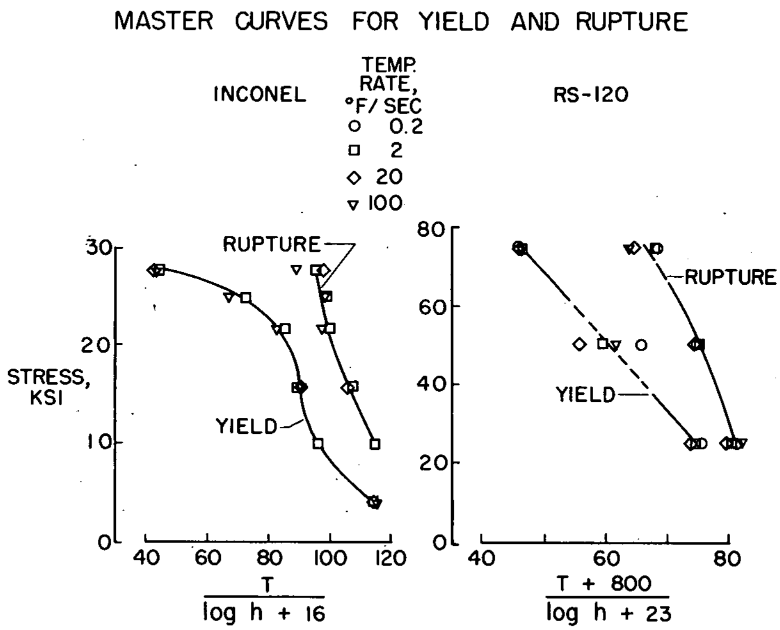
MASTER CURVES FOR YIELD AND RUPTURE
INCONEL
TEMP. RATE, °F/SEC
0.2
2
20
100
RS-120
RUPTURE
YIELD
STRESS, KSI
0
10
20
30
40
60
80
100
120
T / (log h + 16)
0
20
40
60
80
40
60
80
(T + 800) / (log h + 23)

Figure 9