Mechanical Behavior of 6061—T651 Aluminum

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Theme

AN experimental testing program was conducted to determine the effects of stress state and temperature on the mechanical properties of 6061-T651 aluminum. From the data obtained at the yield and ultimate points, a 3-parameter plot was developed based upon the parameters effective stress, effective strain, and the hydrostatic component of stress. This plot illustrates the onset of plastic deformation and the occurance of fracture, and, was obtained solely from the data acquired from uniaxial tensile specimen tested at various pressures and temperatures. Two other loading paths—biaxial tension and torsion—were used to verify the accuracy of the plot. From the test program, data were also obtained regarding the effects of the pressure and temperature environments on the other material properties such as Young's Modulus, Poisson's Ratio, toughness, and ductility.

Contents

The primary purpose of this paper is to discuss the effects of hydrostatic component of stress and temperature on the inelastic behavior of a particular material, 6061-T651 aluminum, and to provide a means for modeling these effects in a form that is acceptable for use by a design engineer.

The influence of the hydrostatic stress state on the inelastic behavior of metals has traditionally been dismissed as insignificant; however, in the case of rock materials, this effect cannot be overlooked.[1] It has also been established by Bobrowsky,[2] Bridgman, [3] and others, that the hydrostatic component of stress state, or pressure, also has much to do with the response of normally brittle-type metals. The coauthor of this paper has shown [4] that a 3-D plot based on the parameters effective stress, effective strain, and the hydrostatic component of stress predicts very well the yield and fracture points for a material undergoing loading of various types. This plot incorporates these three parameters because they are invariant quantities and they include the principal stress ($\sigma_1, \sigma_2, \sigma_3$) and the principal strains ($\epsilon_1, \epsilon_2, \epsilon_3$) from which any state of stress can be determined. The effective stress is defined as

$$2\sigma_e^2 = (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2$$

The second parameter is effective strain which is defined as

$$\epsilon_e^2 = \sqrt{2}/2(1+\mu)$$

$$\{(\epsilon_1 - \epsilon_2)^2 + (\epsilon_2 - \epsilon_3)^2 + (\epsilon_3 - \epsilon_1)^2\}$$

The third parameter used for this plot is the hydrostatic component of stress commonly referred to as the pressure since it would include environmental pressures applied to the system

$$P = -1/3\,(\sigma_1 + \sigma_2 + \sigma_3)$$

Since the hydrostatic pressure causes negative stresses, the negative sign indicates that the environmental pressure is considered a positive quantity.

During the uniaxial tensile tests many material properties were found for 6061-T651 aluminum under high pressure and temperature environments. This data has been tabulated and graphed and is presented in the full paper.

Testing Program: The basic material tests conducted were uniaxial tension, biaxial tension, and torsion. The testing equipment was designed such that each of these tests could be conducted in controllable pressure and temperature environments ranging from ambient to 60,000 psi and 700°F, respectively. The biaxial tension test was accomplished by using an axially loaded internally pressurized thin-wall tube. All testing was considered to be at a static rates.

All specimens used in this program were machined from a single piece of hexagonal bar stock. A hexagon cross-section was used to facilitate the construction of the torsion specimens. An appropriate length on each end of the torsion specimen was left intact to assist in the application of a torsional load. Between these 2 hexagonal sections 2 circular cross-sections were formed. The larger of the 2 circular areas was used as the torque measuring apparatus, and the smaller was used as the test section. A strain gage rosette, mounted on the always elastic large section, was used to monitor the applied torque. The torque-angle of twist data obtained in the experimental program was converted to shear-stress shear-strain parameters by the method suggested by Nadai in Ref. 5. A more detailed description of the equipment design and testing procedure used in this program is given in Ref. 6.

Stress-Strain Curves: From an observation of the actual stress-strain curves, conclusions can be made as to the effect of the pressure on the material. A small but nonetheless definite increase is noted in the yield stress as the pressure rises. The ultimate stress changes more drastically with as much as a 40% increase being observed for a pressure increase of 60,000 psi from atmospheric conditions. As the temperature is increased, however, to a value of 400°F as much as a 40% drop in the ultimate strength was recorded while the yield stress dropped nearly as drastically. Figures 1 and 2 represent the stress-strain curves for increasing pressure and temperature as well as increasing temperature and decreasing pressure. If the temperature were increased to 400°F and the pressure to 60,000 psi from normal room conditions, very little change would be noticed in the ultimate strength. This negligible change can be attributed to the cancelling effects of the temperature and pressure. The pressure attempts to cause a 40% rise while the temperature attempts to cause a 40%

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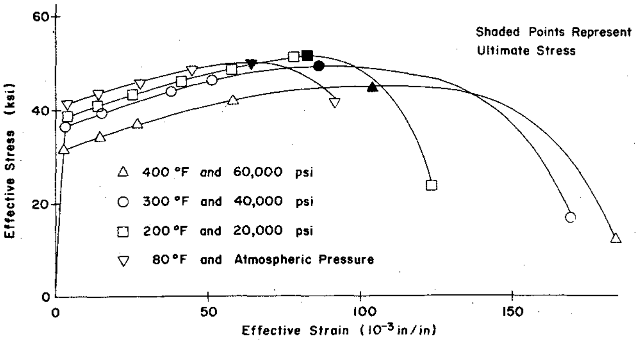

Fig. 1 Effects of pressure and temperature on the stress-strain curve 6061-T651 aluminum (for increasing pressure and temperature.)

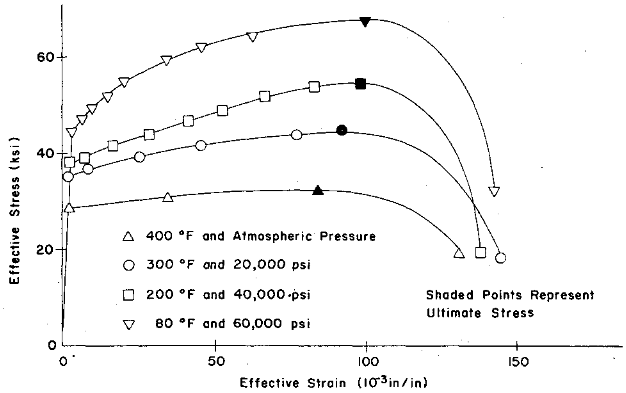

Fig. 2 Effects of pressure and temperature on the stress-strain curve for 6061-T651 aluminum (for increasing temperature and decreasing pressure).

drop. Thus, only a very small drop is noticed in the ultimate stress. Figure 2 shows this effect very clearly. The pressure has very little effect on the yield stress (increased pressure increases the yield strength); however, the temperature increases have a considerable effect on the yield strength especially at the higher values of temperature used during the testing program. Figure 2 points out these combined effects very vividly.

As the pressure increases, toughness increases since both the ultimate stress and the ductility rise in value simultaneously. However, for the temperature portion of the experimental data the toughness decreased as the temperature increased. Temperature increases the ductility while decreasing the strength; however, the increase in ductility is not sufficient enough to offset the reduction in strength. Pressure increases caused as much as a 100% increase in toughness but the temperature only had a 15% effect due to the cancelling effect.

The Yield and Ultimate Data Plot: The effective stress, the effective strain, and the hydrostatic component of stress were calculated for each of the 24 test conditions and plotted on

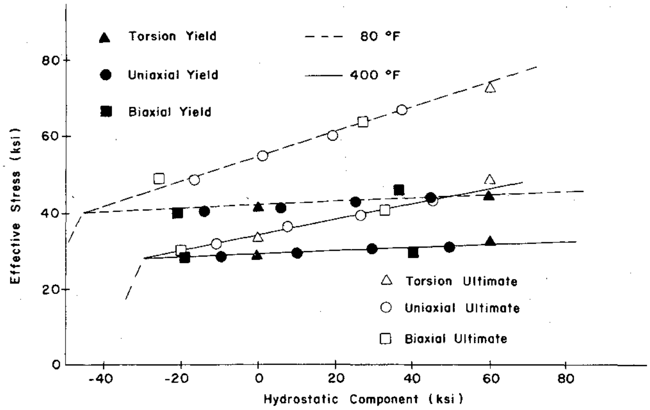

Fig. 3 Yield and ultimate model for 6061-T651 aluminum.

graphs representing the effective stress vs the hydrostatic or mean stress. Temperature was used as a parameter and for this reason there are effective stress-hydrostatic component graphs for two of the four tests temperatures (Fig. 3). The loading paths are determined from the ratio of the effective stress and the hydrostatic component of stress.

It is quite apparent from the figures that the environmental pressure and temperature do indeed affect the yield as well as the ultimate stress of the material. This is indicated by the slope of the ultimate line as well as the shift of the position of the lines as the temperature changes. The nil ductility point (the point where the ultimate and yield lines intersect) is quite apparent for each of the effective stress versus hydrostatic stress curves.

Conclusions: The data tabulated and graphed gives a good indication of how temperature and stress state affect the material properties of a typical engineering material. The 2-parameter yield and ultimate stress data plot formulated from the uniaxial tensile tests predicted very accurate results for the biaxial tension and torsion paths. This accuracy would then indicate that plots of this type would indeed be valuable for predicting yield and ultimate (or fracture) stresses for any given load configuration.

References

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