

High-Strain Rate Constitutive Model Validation of Stainless Steel 22-6-9

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Introduction

It has long been known that the strain rate at which a material is loaded largely affects its mechanical properties. This is because the deformation processes which occur during static or quasi-static loading vary from the deformation processes which occur during dynamic loading. In static/quasi-static loading, the rate of change of the applied force is small, and thus the resulting deformation can be regarded as a series of steps in which the material is in static equilibrium^[1]. During dynamic loading, the rate of change in the applied force is very large, having strain rates on the order of 10^3 - 10^5 s⁻¹. Because of the large rate of strain, waves of deformation rather than evenly distributed deformation pass through the material

Various experiments have been developed to study the behavior of materials under dynamic loading conditions. The Taylor test is one of the oldest and widely used. It involves launching a projectile at a cylindrical specimen and capturing the deformation using high speed photography and velocity interferometry. Although this experiment provides large amounts of information on the dynamic behavior of the material, it is often tedious and time consuming. Thus, a variety of constitutive models, which predict material behavior by factoring in such variables as strain, strain rate, and temperature, have been developed to describe materials under dynamic loading conditions. Of those that have been developed, the von Mises, Steinburg-Guinan, and Johnson-Cook models were examined in the course of the research presented in this paper. The objective of this research was to examine the dynamic deformation behavior of a stainless steel alloy and compare the three aforementioned models with experimental results to determine which of the three presented the best comparison.

Procedure

The material studied in this research project was a cylindrical stainless steel 21-6-9(64% Fe, 20% Cr, 6% Ni, 9 % Mn, all in wt%) specimen . The cylindrical specimen was mounted in Plexiglas along with two triggering pins using an epoxy resin. The front surfaces of the triggering pins were placed approximately 2mm beyond the front surface of the specimen. The specimen was then loaded into the experimental chamber of a gas gun, upon which it was impacted by a projectile at 245 m/s.

Results and Discussion

Upon completion of the impact, still frames of various time steps during the loading event were analyzed to produce Figure 1, which presents the plot of radius vs. axial position for 13.77, 31.7, 54.39 and 67.56 μ s.

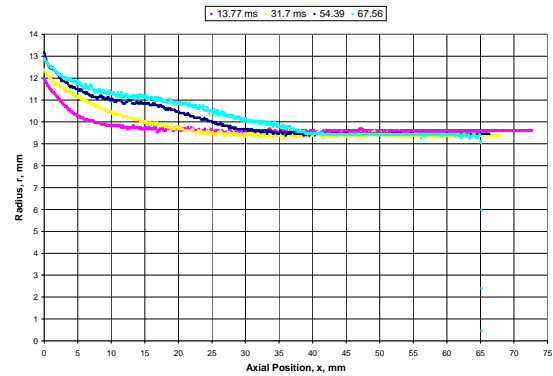


Figure 1 Radius vs. Axial Position

From the plot it is possible to see that two stages of deformation were present. First, the initial impact produced a mushrooming effect on the specimen, followed by a secondary deformation stage, which produced a bulge between 10 and 40 mm along the specimen. The material did not continue to mushroom due to strain hardening imparted on the specimen.

Once the final dimensions of the specimen were determined, computer simulations using Autodyne modeling software were run as comparisons with the experimental results. Table 1 presents the differences in final length and diameter of three constitutive models and experimental results.

Table 1 Final Length and Diameter Comparisons

	Diameter, d_f , mm	Length, L_f , mm	% Δd_f	% ΔL_f
Experimental	25.02	24.92	-	-
Von Mises	35.08	63.32	40.2	2.50
Johnson-Cook	35.83	63.41	43.2	2.33
Steinburg-Guinan	24.88	65.37	0.931	.006

Table 1 shows that the Steinburg-Guinan model produced the best final dimension comparison. This is because the von Mises is a largely simplified model while the Johnson-Cook is an empirical model which requires the input of several experimentally determined parameters

Conclusions

The dynamic deformation of stainless steel 21-6-9 was shown to have two deformation states, an initial plastic region and a strain hardened region. The dynamic behavior of the alloy was most closely simulated by the Steinburg-Guinan model.

References

1. Meyers, M.A., *Dynamic Behavior of Materials*. 1994, New York: John Wiley & Sons, Inc. p.23-25.