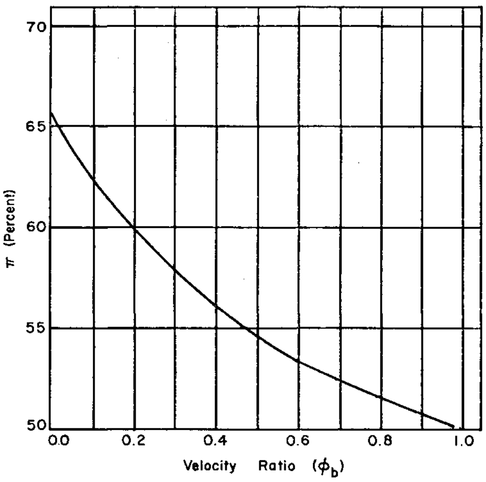

Fig. 3 Percentage of total diffused heat π contained in faster stream.

References

[1] Miles, J. B., "Stanton number for separated turbulent flow past relatively deep cavities," Ph. D. Thesis, Mechanical Engineering Dept., Univ. of Illinois (1963).

[2] Korst, H. H. and Chow, W. L., "The compressible turbulent jet mixing between two streams at constant pressure," Engineering Experiment Station, Univ. of Illinois, M. E. TN 393-2 (1963).

[3] Goertler, H., "Berechnung von aufgaben der freien turbulenz auf grund eines neuen naherungsansatzes," Z. Angew. Math. Mech. **22**, 244–254 (1942).

Temperature Yield Strength Correlation in Hypervelocity Impact

R. Piacesi,* R. H. Waser,† and V. C. D. Dawson‡
U. S. Naval Ordnance Laboratory, White Oak, Silver Spring, Md.

Nomenclature

V_c = crater volume
V_p = projectile volume
V_0 = impact velocity
C_0 = sound speed in target

Introduction

A PREREQUISITE for the complete formulation of the effects of high-velocity particles impacting on a thick target is the understanding of the basic physical processes involved. Each of the large number of variables which appear to influence the resulting crater dimensions and their interdependence must be evaluated.

Although it is generally recognized that some mechanical strength property of the target and its temperature dependence is important in the cratering process, no experiments have tied down this temperature strength correlation. An investigation was made to determine whether there is an exact correlation between the target yield strength and the target temperature.

Presented as Preprint 64-436 at the 1st AIAA Annual Meeting, Washington, D. C., June 29–July 2, 1964.

* Research Aerospace Engineer. Member AIAA.
† Research Aerospace Engineer.
‡ Aeronautical Research Administrator. Member AIAA.

Experiment

It has generally been known that the crater size is dependent upon on the mechanical strength of the target. Experiments also have been conducted demonstrating that heating the target caused larger craters to result from impacts.[1] It also has been pointed out that, when the temperature is varied, anomalies in the crater dimensions appear at temperatures where anomalies occur in the strength of the target matrial.[2] Others have shown that a favorable graphical comparison exists between the cratering efficiency and the target tensile strength as a function of temperature.[3] The question arises then as to whether an exact correlation in crater size exists between the target temperature and a mechanical property, such as the yield strength. For example, consider cratering in two targets of the same material but different yield strengths. If the yield strength of the two targets were made equal by raising the temperature of the higher yield strength target, would equal size craters be obtained for a given impact?

The experiment consisted of firing $\frac{1}{4}$-in.-diam aluminum spheres into 2-in.-thick, 8-in.-diam aluminum targets. The targets were of 7075-T6, 2017-T4, and 7075-0 aluminum, having room temperature yield strengths of 68,400, 38,700, and 17,000 psi, respectively. (These values were obtained from yield strength tests made on samples of the target material stock.) A range of impact velocities was covered for each of the three different targets at room temperature, and the resulting craters were measured. Impacts were made on four 7075-T6 targets, two of which were heated to 380°F and two to 500°F, having true yield strengths of 40,500 and 20,500 psi, respectively, and on one 2017-T4 target heated to 357°F, having a true yield strength of 25,500 psi. (These yield strength values also were obtained from curves constructed with data from yield strength tests made over a range of temperatures.)

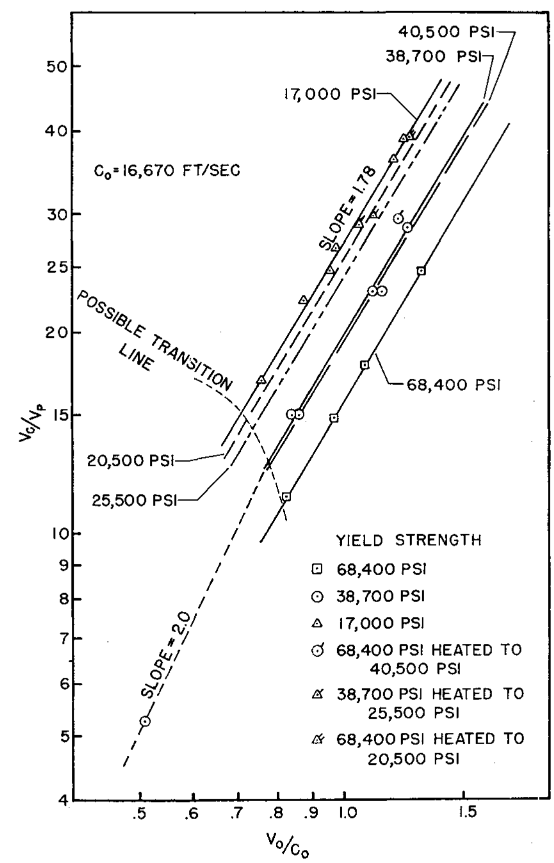

Fig. 1 Yield strength correlation.

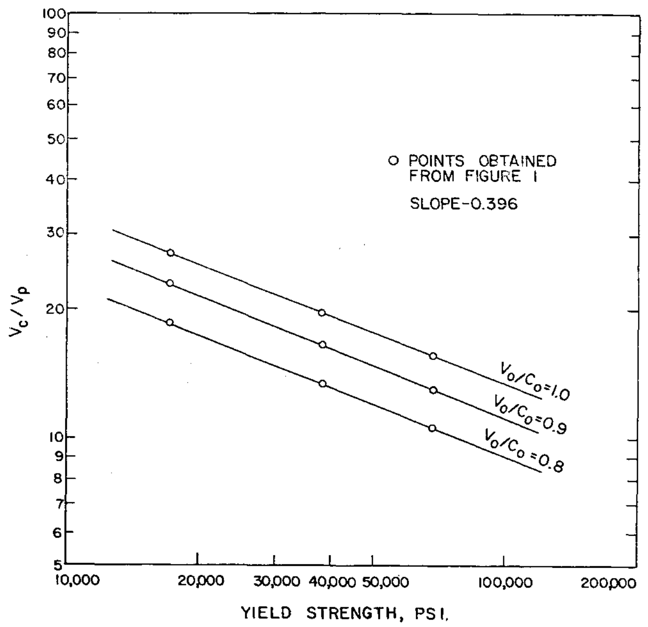

Fig. 2 Crater size dependence on yield strength.

The crater volume was measured with reference to the original surface using a low surface tension fluid and a hypodermic syringe. The depth was measured with a depth micrometer and the diameter was measured with an optical comparator. The correlation was made with the crater volume because of the large scatter in the depth. This scatter was due to the roughness of the craters in the more brittle 2017-T4 and 7075-T6 targets.

A log-log plot of the parameters V_c/V_p against V_0/C_0 is shown in Fig. 1. The room temperature constant yield strength lines indicated that the V_c/V_p was dependent on the -0.396 power of the yield strength at constant velocity (Fig. 2) for velocities from 12,600 to at least 21,750 fps. An interpolation was made for the lines of constant yield strength for the heated target conditions. The experimental temperature yield strength correlation is seen to be very good with the exception of one point for one of the 7075-T6 targets, which was heated to 380°F, in which case the point is high. It should be noted that the slope of the constant yield strength lines is not 2 but 1.78, indicating that a transition region has appeared. This would mean that we have reached a region where strength effects may be starting to diminish in importance. The one low-velocity shot into the room temperature 2017-T4 target did not fall on the 1.78 slope line, and therefore was assumed to be in the kinetic energy dependent region. A line of slope equal to 2 was drawn through this point to observe where the transition point might be. The transition point for the 2017-T4 target is indicated to be at 13,000 fps. When the point is reached where the strength effects can be ignored, the slope should be equal to 1.0,[4] and the lines of constant yield strength should converge into only one line. In order for the lines to converge, the transition point should occur at lower velocities in the lower yield strength targets. A line indicating the possible transition point as a function of yield strength is shown in Fig. 1.

It was intended to further substantiate the temperature yield strength correlation by firing more shots into heated targets. However, sabot problems that depleted the supply of target material prevented a continuation of the test at the present time. It is the intention of the authors to continue this investigation more thoroughly with a new supply of target materials.

The test facility used for this program was the Naval Ordnance Laboratory hyperballistics range no. 2. This range is a 66-ft-long, 3-ft-diam tube, which can be evacuated

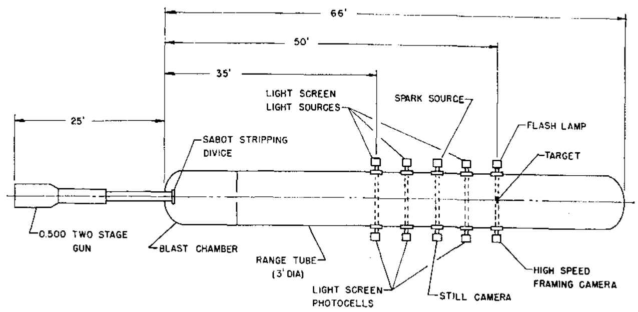

Fig. 3 Sixty-six-foot hyperballistics range no. 2.

to less than 1 mm Hg pressure and which is equipped with projectile velocity measuring instrumentation consisting of light screens and time interval counters. A Beckman-Whitley 192 high-speed framing camera and a flash tube light source were installed for this program to photograph the impact of the projectile with the test targets. A 0.500-in. two-stage light-gas gun was used to accelerate the 0.250-in. aluminum sphere projectiles to velocities up to 22,000 fps. Figure 3 shows the range facility setup schematically. The still camera with spark light source is associated with the velocity measuring system to provide a positive check on its operation by photographing the projectile that triggers the light screens.

For the shots in which the target was heated, a 1000-w electric Calrod heater was fastened to the back side of the target, and temperature was monitored by making use of a thermocouple placed in a hole drilled in the target. It was experimentally determined that the temperature gradient in the target and the inaccuracy in measuring temperature amounted to no more than 3°F. Before firing, the projectiles were mounted in bore size lexan sabots, which were stripped off and deflected as they left the muzzle of the gun. The range tube pressure in all cases was decreased to less than 2 mm Hg pressure to prevent the projectile from ablating before its impact with the target.

Microhardness measurements were made around the crater of the unheated aluminum (7075-0) target as shown on Fig. 4. The shape of the hardness readings for the "C" traverse is shown in Fig. 5. The other traverses had a similar shape, but the amount of softening indicated by the first reading nearest the crater was less pronounced.

The "C" traverse seems to indicate that sufficient heat was generated during the impact to cause recrystallization in a thin layer, estimated to be 0.015 in. thick at the bottom of the crater. The zone farther away from the crater shows

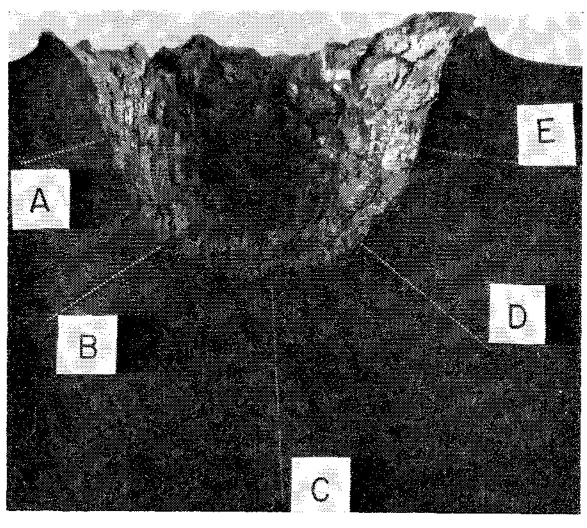

Fig. 4 Microhardness measurements.

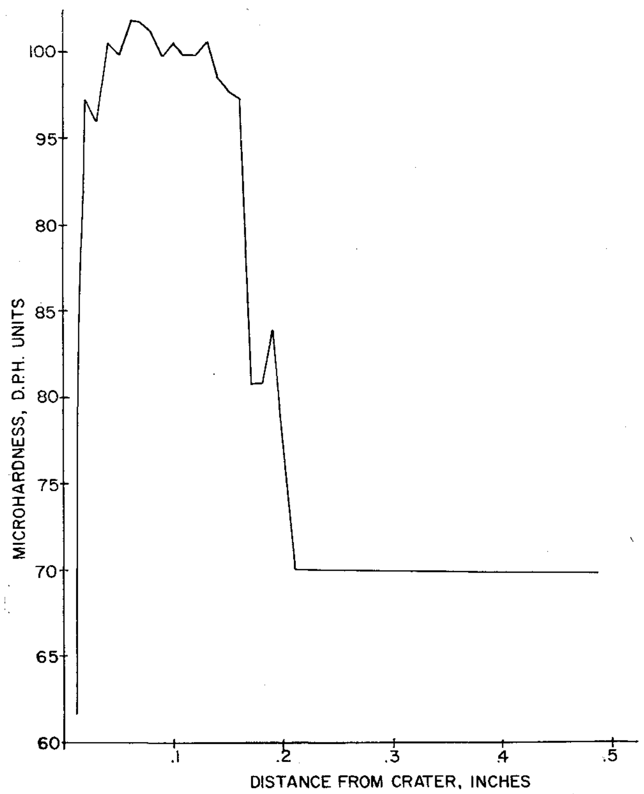

Fig. 5 Microhardness as a function of radial distance from crater.

higher hardness indicative of strain hardening without recrystallization.

Measurements of hardness on the heated targets indicate a more general softening around the crater, the depth of softening away from the crater being greater than in the case of the unheated targets. However, even the heated targets showed a very thin layer near the crater which was considerably softer than the material more removed from the crater.

Conclusion

It is concluded that there is an exact correlation between temperature and yield strength. The crater volume is seen to be dependent on the -0.396 power of the yield strength for impacts of aluminum spheres on semi-infinite aluminum targets in the velocity range from 12,700 to 21,750 fps. From a transition point, at about 13,000 fps and up to at least 21,750 fps, the crater volume is not dependent on the kinetic energy of the projectile but rather on the velocity to the 1.78 power, indicating that the strength effect on the cratering process may be diminishing above a velocity of 13,000 fps. Microhardness readings seem to indicate that sufficient heat was generated during the impact to cause recrystallization in a thin layer, estimated to be 0.015 in. thick at the bottom of the crater.

References

[1] Ferguson, W. J. and McKinney, K. R., "The influence of temperature elevation on the penetration of missiles in copper targets," Naval Research Lab. Rept. 5407 (November 1959).

[2] Allison, F. E., Becker, K. R., and Vitali, R., "Effects of target temperature on hypervelocity cratering," Fourth Hypervelocity Impact Symposium, Vol. 1 (April 1960).

[3] Rockowitz, R., Carey, C. A., and Dignam, J. F., "Hypervelocity impact of heated copper," Fifth Symposium on Hypervelocity Impact, Vol. 1 (April 1962).

[4] Bjork, R. L., "Effects of a meteoroid impact on steel and aluminum in space," TR P-1662, Rand Corp., Engineering Div. (December 1958).

Longitudinal Wave Propagation in Liquid Propellant Rocket Motors

Sanford S. Hammer* and Vito D. Agosta†
Polytechnic Institute of Brooklyn, Farmingdale, N. Y.

Introduction

LONGITUDINAL wave propagation studies are being conducted in a liquid propellant rocket motor in order to define the parameters that determine whether an input disturbance will attenuate or amplify. Since combustion instability is a measure of the relative amounts of energy accumulation in a cavity in contradistinction to the energy dissipation from the cavity, the mechanisms that allow such behavior should be analyzed in detail. Particular emphasis must be placed upon the interaction of pressure waves and the fluid dynamic field.

Consider the case where the relaxation times of significant processes are in excess of the wave residence time in a volume element of a liquid propellant rocket motor. It can be envisaged that the toe of a passing wave in a reacting droplet system can increase the rate of evaporation, which couples as a mass source to the heel of a passing wave, thus producing amplification. It can further be seen that, for a long relaxation time, the mass source can generate wavelets that coalesce as they propagate and ultimately overtake the initial wave that caused the disturbance, thereby causing amplification. In addition, as a wave propagates in a gas, it deforms. A compression wave will steepen in a decelerating flow; an expansion wave will broaden in an accelerating flow. A compression wave in an accelerating flow and an expansion wave in a decelerating flow will either broaden or steepen, depending on the wave slope and the velocity gradient of the gaseous medium. Therefore, as a wave moves in a rocket chamber, it will change its geometry, which then alters its residence time in a volume element. In addition, the energy in a wave is a function of its velocity and waveform. Thus, the wave slope assumes a major role in that it determines, by modifying the effective wavelength and amplitude, the nature of the energy or mass coupling to the propagating wave and the ultimate stability of the system.

This note presents some recent experimental data on wave-shape behavior in a liquid rocket motor in addition to measurements of the effect of Mach number on the frequency of wave propagation.

Experimental Equipment

Experiments are being conducted in a 2-in.-diam 500-lbf nominal thrust, JP-5A-Lox rocket motor. The injector is of the shower-head type with 16 fuel and 16 oxidizer orifices. The total propellant flow is 2.37 lbm/sec at an oxidizer-fuel ratio of 2.79. The chamber length is 22.5 in. measured from the injector face to the start of the converging nozzle. The nozzle contraction ratio is 1.5, resulting in a high Mach number profile through the chamber. High frequency-response pressure transducers (Photocon model no. 352) are flush-mounted in the chamber at 3, 13, and 21 in. from the injector face. Data are recorded on magnetic tape at 60 in./sec and played back at 1 in./sec into a recording oscillograph with a paper speed of 25 in./sec. Approximately

Received June 30, 1964. The results presented in this paper were obtained in the course of research sponsored by the Air Force Office of Scientific Research under Contract AF 49(638)-1263. The authors wish to acknowledge William T. Peschke for his valuable assistance in the performance of the tests in this investigation.

* Research Associate, Aerospace Engineering, Propulsion Research Laboratory. Member AIAA.

† Professor of Aerospace Engineering, Propulsion Research Laboratory. Member AIAA.