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POSTSHOCK SPECTRAL RADIANCE MEASUREMENTS IN NICKEL AND NICKEL/ALUMINUM POWDERS

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Because of complications associated with temperature heterogeneities in shocked metal powders, time-resolved radiation pyrometer measurements of shock temperatures in powders with particle sizes greater than a few tens of microns cannot be made under normal laboratory conditions with uniaxial loading durations limited to about one microsecond. Fortunately, for highly porous, reactive powders, the difference between shock and postshock temperature is negligible. For loading conditions similar to those that have yielded reaction products in recovery experiments, there is no evidence of any chemical reaction in a coarse (-325 mesh) nickel/aluminum powder mixture within the first 6 μs of shock arrival, based on constraints on postshock temperatures provided by thermal radiation measurements. This result is in contrast to that for a micron-sized nickel/aluminum mixture, for which there is evidence of significant reaction on a time scale of 100 ns under similar shock loading conditions.

1. INTRODUCTION

There are a number of complications associated with the radiative measurement of shock temperatures in powders. Foremost is the fact that radiation pyrometer measurements are dominated by the highest temperatures present in a sample. When a heterogeneous medium such as a powder is shocked, the temperature distribution immediately behind the shock front is not uniform because of pore collapse and differential plastic deformation of powder grains. The intensity of thermal radiation emitted from a material is dictated by the Planck function, so it is a very strong function of temperature. Most of the measured visible and near infrared light from a heterogeneously heated material is emitted from the hotter regions. Until sufficient time has elapsed for thermal diffusion to cause the temperature to become uniform, it is the highest localized temperature of a shocked powder sample that dominates the measurement, not its equilibrium, or "mean-bulk" shock temperature,[1] and the initial color temperature can be from two to ten times higher than that calculated assuming homogeneous heating.[2]

It is reasonable to expect the spatial scale of temperature heterogeneity to be determined by the scale of physical heterogeneity of the initial powder; the temperature should vary over distances on the order of particle size. This expectation has been borne out by measuring thermal radiation emitted from shocked powders with different particle sizes. When nickel powder with a particle size distribution in the range between 44 and 74 μm is shocked,[3] it takes significantly longer for thermal radiation (presumably from cooling heterogeneities) to decay than when nickel with a 2 μm typical particle size is shocked under similar conditions.[4,5] Spectral radiance histories for shocked nickel powders with two different mean particle sizes are plotted in Fig. 1.

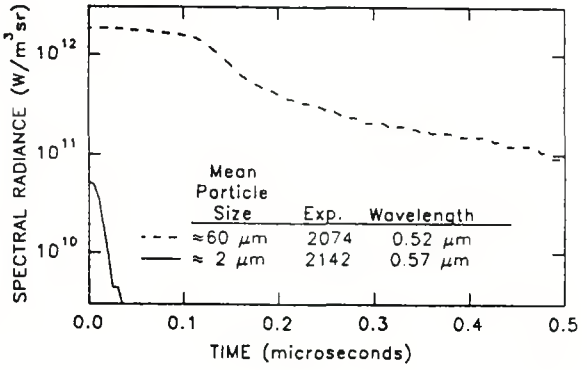

FIGURE 1
Time-resolved spectral radiances for nickel powders with different particle size distributions under uniaxial shock loading.

DISCLAIMER

For experiments on Sandia's 63-mm bore compressed gas gun, shock durations and uniaxial strain conditions cannot be sustained for much more than one microsecond under the target geometries required for forward ballistic shock temperature measurements in powders for which light is collected from a 19-mm diameter area. For shocked metal powders with mean particle sizes in the ten μm range, the approach to thermal equilibrium is not complete on this time scale, so radiation pyrometry cannot be used to make direct measurements of equilibrium shock temperatures without extending the shock duration. The coarser powders that have been used in shock recovery experiments[6,7] (in which product phases have been found in the recovered samples) are thus not amenable to time-resolved shock temperature measurements. However, for highly porous powders that react exothermically when shocked, the post-shock temperature does not differ significantly from the shock temperature.[8] In addition, Horie and Kipp[9] have suggested extending temperature measurements to cover a time period from a few μs to as long as 10 μs in order to further constrain kinetic parameters associated with chemical reactivity. The present work represents the first attempt to measure the post-shock temperature of a reactive powder by extending the time interval of spectral radiance measurements.

2. EXPERIMENTAL

Postshock spectral radiance experiments were carried out on two different samples: 1) flaky nickel of -325 mesh size (AESAR 13788), and 2) a mechanical mixture of this nickel with rounded -325 mesh aluminum (AESAR 11067). The mixture had a molar ratio of 3 Ni to 1 Al, which corresponds to the stoichiometry of the Ni_3Al compound that has been shock-synthesized. The mixture is identical to that used in recent recovery experiments[7] in which shock-induced reactions were observed. The pure nickel powder provided a control experiment; because it is inert its shock temperature cannot include a chemical energy contribution.

The powder compacts were pressed into modified "Momma Bear" recovery fixtures to provide conditions approximating those achieved in recovered samples.[10] The compact densities were kept as low as possible in an attempt to maximize the conditions that would lead to shock-initiation of a reaction. The center portion of the rear plug of the copper fixture was replaced by a 19 mm diameter sapphire window to allow time-resolved measurement of thermal radiation at four wavelengths in the visible and near infrared.[1] These fixtures were directly impacted by copper flyer plates launched at velocities of about 1.2 km/sec from a gas gun.

The present target configuration (Fig. 2) differs significantly from those used in conventional shock compression experiments in that no attempt was made to achieve uniaxial strain conditions. Like the recovery fixtures whose loading conditions it was designed to simulate,[10] the loading and unloading are dominated by radial flow. However, the postshock temperature depends primarily on the initial porosity, the strength of the initial shock wave, and the amount of reaction, not on the direction or path of unloading. Because the principal purpose of these experiments was to determine whether the powder had reacted on the time scale of the measurements, the variation in conditions across the sample were of secondary importance. A qualitative picture of the compression process has been obtained from a numerical simulation that was carried out for a target of similar design that was used in previous optical measurements of shocked nickel/aluminum compacts.[11]

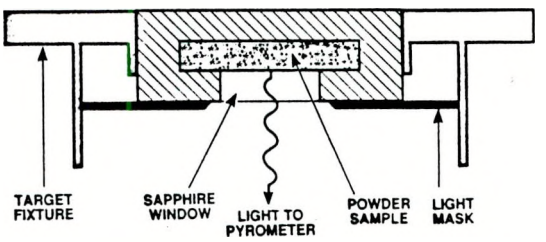

FIGURE 2
Experimental configuration; light radiated from the powder-sapphire interface is measured at four wavelengths.

3. RESULTS AND DISCUSSION

Fig. 3 presents the time-resolved spectral radiance data from one experiment on each type of powder. The time is referenced to the time at which light was first detected (when the earliest shock arrives at the powder-sapphire interface). Gaps in the data indicate off-scale or below-scale signals (because of the strong dependence of spectral radiance on shock temperature, the values can change by up to four orders of magnitude in less than a microsecond). Only the data for the first 6 μs are presented; after that time there may be a significant contribution from spurious light that can be indirectly scattered into the optical system from other parts of the target. In both experiments, all four spectral radiances rapidly dropped to nearly constant values within 5 μs. This observation is consistent with an asymptotic approach of temperature heterogeneities to the mean bulk temperature through thermal transport processes, so the measured radiances can be taken as an upper bound to that which would be radiated after equilibrium has been reached. Unlike spectral radiance measurements of micron-sized powders under uniaxial strain conditions (Fig 4), there is no significant difference between the nickel and nickel/aluminum experiments.

Temperature and effective emissivity histories determined from a least squares fit to a graybody distribution function[1] are plotted in Figs. 5 and 6. These histories are remarkably similar; the graybody temperatures rapidly drop to a nearly constant value in the 2300 to 2400 K range. However, the effective emissivities remain very low in both cases, indicating either that: 1) the samples are radiating at this temperature from only a small fraction of the observed area, or 2) the spectral radiances from the samples drop to values below a weak background level of scattered light. The first possibility is consistent with streak camera records under similar conditions showing a concentration of hotter shocked material on the axis of symmetry[11]. In either case, the spectral radiances lie below the values associated with temperatures and emissivities consistent with a significant degree of reaction.

The present results are in apparent contrast to the results of recovery experiments by Song and Thadhani[7], who detected significant quantities of intermetallic nickel/aluminum alloys in recovered specimens. This discrepancy may be due to the differences between the two experiments in details of shock loading. It is also possible that the temperatures associated with the reaction are lower than expected, because the high temperature thermochemical data on nickel/aluminum alloys are limited.[12] Another interpretation is that the reaction takes place, but on a much longer time scale.

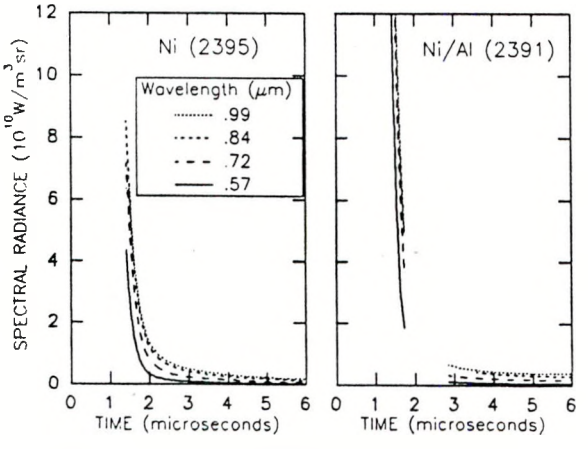

FIGURE 3
Time-resolved spectral radiances from -325 mesh nickel and nickel/aluminum mixture, shocked using configuration in Fig. 2

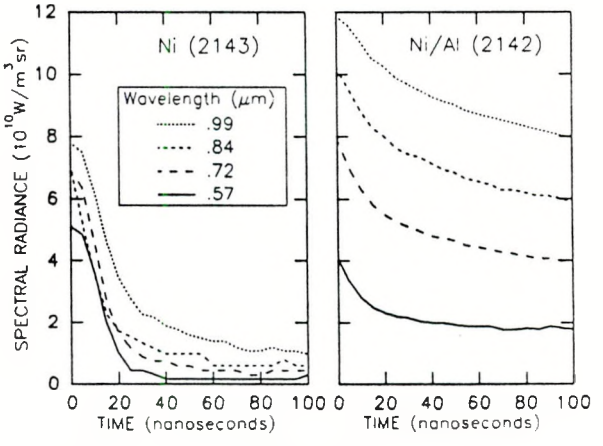

FIGURE 4
Time-resolved spectral radiances from powders with typical particle sizes of 1 to 2 μm under uniaxial shock loading

4. CONCLUSIONS

There is no evidence from spectral radiance measurements that a -325 mesh mixture of nickel and aluminum powder exhibits significant reaction during or within 6 μs of shock compression--even under the most favorable gas gun loading conditions attainable. Shock temperature measurements have previously indicated that a partial reaction takes place within 100 ns of uniaxial shock-loading of a powder with a much smaller particle size[5]. For the nickel/aluminum system, particle size appears to be an important parameter controlling the rate and/or sensitivity of shock-induced chemical reactions, with finer-grained powders reacting more readily than coarser powders.

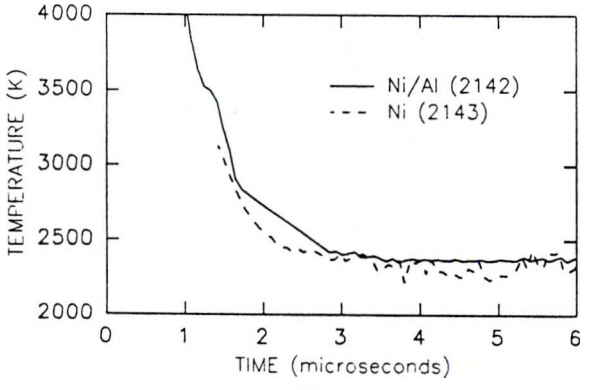

FIGURE 5
Time-resolved graybody temperatures
for shocked nickel/aluminum and nickel.

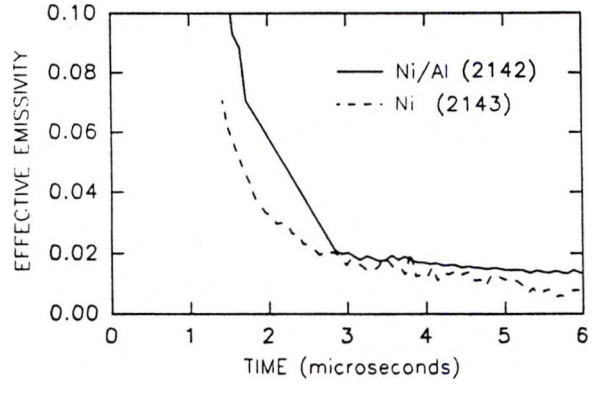

FIGURE 6
Time-resolved effective emissivities
for shocked nickel/aluminum and nickel.

Because of low levels of spurious light that can interfere with spectral radiance measurements at times greater than a few microseconds after impact, it may be more appropriate to use this method to investigate reactive powders with much larger heats of reaction, such as aluminum/metal oxide thermites, for which thermal spectral radiances would be much larger than those reported here, even for small amounts of reaction.

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