# Air blast characteristics of laminated al and NI-AL casings

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# AIR BLAST CHARACTERISTICS OF LAMINATED AL AND NI-AL CASINGS

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**Abstract.** Air blast characteristics of Al and Ni-Al laminated materials were experimentally investigated in a 23 m$^3$ closed chamber. Ni and Al foils, 50 to 100 micrometers in thickness, were rolled and compacted to form a cylindrical casing with a density of 95% TMD through an explosive formation technique. Charges were prepared using 2 kg C4 explosive packed in the laminated casing to a metal-explosive mass ratio of 1.75. The blast pressure history measured on the chamber wall showed a double-shock front structure with a precursor shock followed by the primary blast. The front peak pressure for the Ni-Al cased charge reaches 1.5-2 times that of the Al cased, consistent with the larger fireball recorded for the Ni-Al cased. The long time quasi-static explosion pressure (QSP) from the Ni-Al cased charge is 0.8 of that of the Al cased, due to half of Al mass in the Ni-Al.

**Keywords:** NiAl, fragmentation: reactive metal particles, blast wave, reactive casing.
**PACS:** 47.40.Rs, 47.40.Nm, 62.20.mm.

## INTRODUCTION

Fragments from a reactive structural material (RSM) casing can introduce a secondary energy release through fragment combustion to enhance air blast [1]. Idealized RSM must possess both high energy density and high material density. A composite of nickel (Ni) and aluminium (Al) could serve as an RSM prototype due to the Ni material density (8.86 g/cc) and high energy content of Al. Ni-Al bimetallic reaction may provide additional heat source to promote Al reaction in air [2]. The heat of reaction for the NiAl product is 1.380 kJ/g; for the $Ni_3Al$ product, it is 0.4419 kJ/g in liquid phase and 0.7647 kJ/g in solid phase. Reaction of nanometric laminated Ni-Al can be found in a number of studies where ignition occurs at 450-900 K depending on the layer thickness/spacing [3-4]. This reaction threshold temperature is near the Al melting to facilitate diffusion mixing of Al and Ni. From a structural material point of view, the current work applies laminated Ni-Al made of tenths-of-micrometer thick layers to gain an understanding of the bimetallic laminated material performance in explosion and blast.

## EXPERIMENTAL PROCEDURE

Experiments were conducted in a 3 m internal diameter, 23 m$^3$ cylindrical steel chamber [1]. A 12.3 mm thick replaceable layer of steel was clad on the internal surface of the chamber wall to prevent its damage from high-speed case fragments. Three Endevco piezo-resistive pressure transducers were installed on the chamber cylinder wall indicated by B, C and D, where gauge C was located at the middle with an interval of 0.7 m between the gauges. High-speed video photographs were taken from a window located at the center of the right end wall of the chamber. The charge was

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suspended in the center of the chamber and the chamber was then closed with a local atmospheric air pressure of 91.8-92.8 kPa and temperature of 9 to 15 °C. The residue fragments and solid products of explosion were recovered after each test.

A 2 kg C4 explosive was chosen, with the detonation mechanical energy, pressure and velocity of 5.74 kJ/g, 25 GPa, 8.0 km/s according to the Cheetah code 2.0 (Lawrence Livermore National Laboratory) with the BKWS EOS. The charge was contained in a laminated case comprised a 10.0 cm inner diameter, 16.25 cm long cylindrical tube (2.6 kg) and two solid Al end plates (0.45 kg each), with a case/charge mass ratio of $M/C = 1.75$.

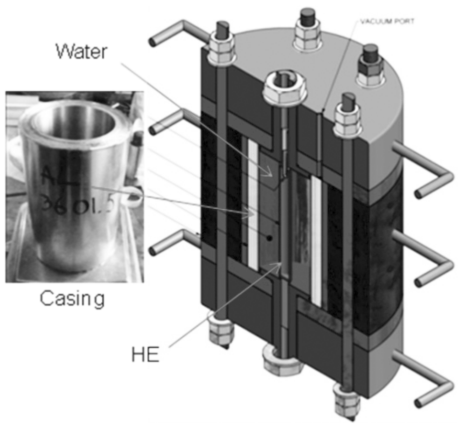


**Figure 1.** Laminated casing preparation in an explosively compressed water chamber.

**Figure 2.** Final laminated casing after compaction by explosively compressed water and machining.

The Ni-Al laminated case comprised repeated one 50 μm thick Ni layer and two 75 μm thick 3003 Al layers, which results in a mass ratio of Ni:Al = 1:0.94. Layered Al was used to make baseline cases in layer thickness of 75 μm and 100 μm, respectively. The laminates were first rolled into a cylindrical shell and then inserted in a water chamber (Fig. 1). Cylindrical detonation from a high explosive at the axis of the chamber compressed water that further compacted the laminated shell to reach a density of 95% of TMD (i.e., 4.3 g/cc for Ni-Al). The compacted shell was machined to the final casing with top and bottom solid Al end plates connected with screws (Fig. 2).

## RESULTS AND DISCUSSION

The high speed photographs in Figs. 3 and 4 show the case expansion, fragmentation and subsequent fireball from the detonation of a baseline 75 μ-Al and Ni-Al laminated cased charges. Detonation is initiated from the top by an RP83 detonator. The casing fracture and fragmentation occur at a failure radius $R_f \approx 2.2R_0$ at about 60 μs ($R_0$ - initial case outside radius), slightly larger than that of a solid case where $R_f \approx 2R_0$ [1]. The reacting fragments can be seen in Figs. 3 and 4 through their brightness. The photographs beyond 900 μs display the later afterburning through reflected shocks and turbulent mixing. It is noticeable that the fireball after case fragmentation is larger for the Ni-Al cased charge than for the Al cased.

Figure 5 shows an example of recovered residue fragments and detonation/afterburning solid products from the Ni-Al cased charge. The thin fragments were from the laminated cases, whereas the thick ones from the solid ends. Fragments include Ni, Al and a small fraction of Ni-Al reaction products as indicated in the SEM analysis. Considerable amount of Al fragments solidified after being molten. Two examples of recovered fragments from the same trial shown in Fig. 5 are given in Fig. 6, which shows bimetallic product pieces from the laminated Ni-Al. The total mass of fragments above 1 mm in size is 1.0 kg for both laminated Ni-Al and 75-μ Al cases.

Figure 7 provides the normally reflected wave front pressure histories measured at gauge C. The shock front of the laminates-cased charges exhibits a two-shock structure, where a precursor shock exists in front of the primary shock, similar to that of the solid RSM cases [1]. The pressure front from the 100-μ Al cased charge propagates slower than that of the baseline 75-μ Al cased. The Ni-Al cased charges show much higher front peaks than the baseline 75-μ Al cased. The high peak pressures from the Ni-Al cased charges are consistent with their larger fireball as discussed above in Figs. 3 and 4. It is to be examined if the enhanced blast performance is attributed to the bimetallic reaction or more to the promotion of Al reaction in air due to presence of Ni.

Figure 8 gives the long time reverberating pressure wave histories approaching quasi-static pressures (QSP). Within the first 10 ms between the first and fourth reflections on the chamber wall, the pressure rise for the baseline 75-μ Al cased charge achieves a factor of 1.6 versus the bare charge. This indicates rapid combustion of a considerable amount of small fragments. The final QSP for the same cased charge reaches a factor of 2 versus the bare charge. The QSP of the 100-μ Al cased charge is decreased by 9%, while the Ni-Al

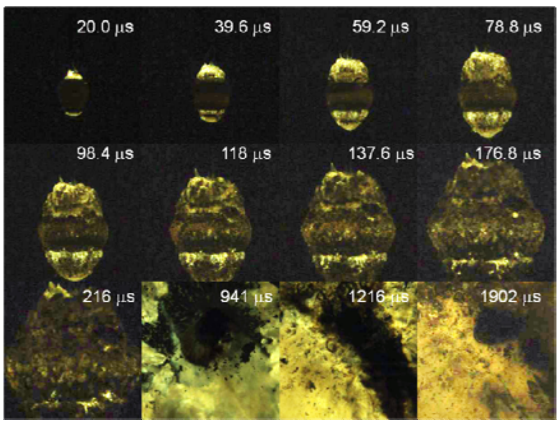


**Figure 3.** Explosion of a 10 cm I.D., 75μ-Al laminated cased C4 charge with *M/C* = 1.75 (#11165A).

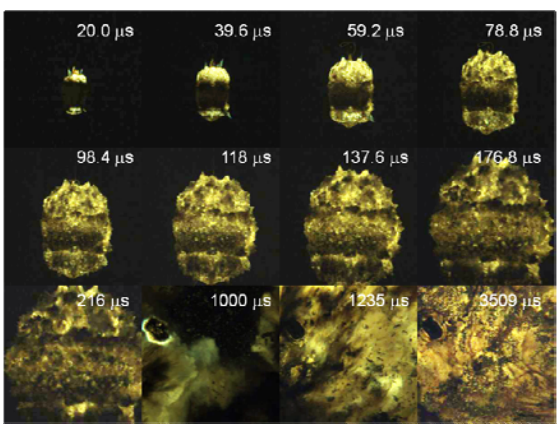


**Figure 4.** Explosion of a 10 cm I.D., laminated Ni-Al (a 50μ-Ni and two 75-μ Al layers) cased C4 charge with *M/C* = 1.75 (#11164A).

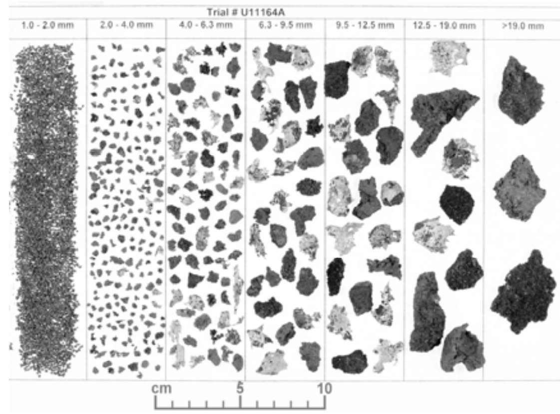


**Figure 5.** Recovered fragments (≥ 1 mm) of a laminated Ni-Al case including reaction products (#11164A).

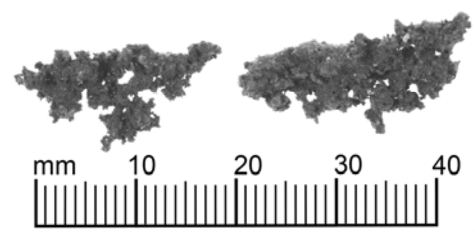


**Figure 6.** Examples of metallic product fragments from the Ni-Al case trial #11164A.

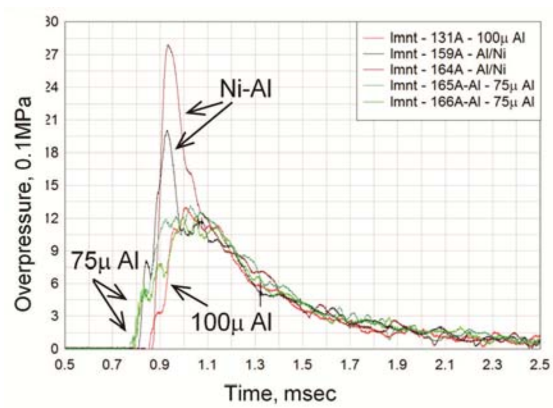


**Figure 7.** Normally reflected pressure fronts (at gauge C) from 75μ-Al, 100μ-Al and Ni-Al laminated cases.

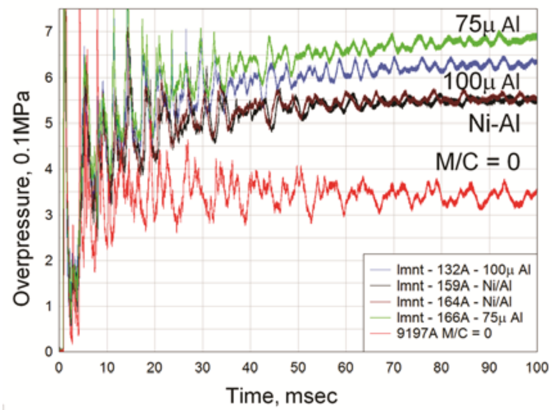


**Figure 8.** Comparison of long time pressure histories (at gauge B) between 75μ-Al, 100μ-Al and Ni-Al laminated cased charges.

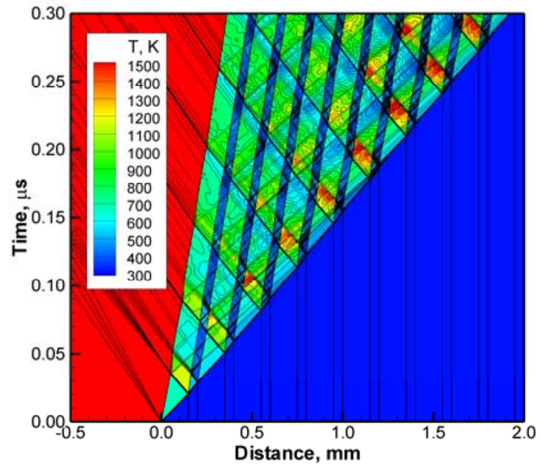


**Figure 9.** 1D wave diagram with temperature (colors) and density (lines from 2 to 11 g/cc) of the early shock reverberating process in 150μ-Al (green) and 50μ-Ni (blue) laminates driven by C4 detonation (red).

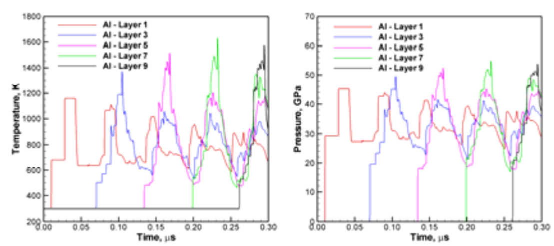


**Figure 10**. Lagrange gauges in every second Al layer during the early reverberating-shocked process of the laminated configuration shown in Fig. 9.

cased charge by 20% with respect to the baseline 75-μ Al cased, due to the mass of Al reduced to half in the Ni-Al casing.

Ni-Al reaction seems to be associated with bimetallic diffusion that largely depends on Al melting [3-4]. At the atmospheric condition, Al has a melting point of 933 K while the Ni melting point is 1726 K. To understand the heating behavior of Al, a 1D hydrocode (Chinook from Martec Ltd.) simulation was conducted for the early shock reverberating compression of Ni-Al laminated layers driven by the C4 detonation. The computed wave diagram is shown in Fig. 9, assuming an infinitely thick C4 slab adjacent to 10 bi-layers of Al (150 μm) and Ni (50 μm). The temperature and pressure in an Al layer reach the peak after the shock reflection on the downstream Ni layer (Fig. 10). This peak temperature and pressure increase with layer number as the shock front propagates outwards, due to interactions with the compression waves transmitted from the upstream Ni layers. The peak temperature in Al layers reaches 1200-1500 K, higher than its atmospheric melting point but lower than the melting point at the corresponding peak pressures of 45-50 GPa (i.e., 2700-3000 K based on the high pressure melting theory [5]).

Future studies include chemical analysis of metal products, mechanical property analysis of the laminated case and extension to various metal combinations of laminated cases.

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