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To cite this article: J Chen *et al* 2020 *J. Phys.: Conf. Ser.* **1507** 062004

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# Metallic reactive materials application in fragmentation warhead

J Chen<sup>1</sup>, Y J Chen<sup>1</sup>, X Li<sup>1</sup>, Zh F Liang<sup>1</sup>, T Zhou<sup>1</sup> and Ch Xiao<sup>2</sup>

<sup>1</sup>Xi'an Modern Chemistry Research Institute, 168 Zhangba East Road, Yanta District, Xi'an 710065 Shannxi, China

<sup>2</sup>China North Chemical Industries Group CO., LTP, Beijing 100089, China

Email:chenjin204s@163.com

**Abstract.** The composition, structure, manufacturing process and properties of Metallic reactive materials are introduced. The typical ternary mixture of Ni-Al-W have high density of 7.37g/cm<sup>3</sup> and static tensile strength of 228MPa, which make the reactive fragments gain high penetration capability to perforate the target's skin and can survive under explosive. The Ni-Al-W fragments undergo intermetallic reaction and oxidation reaction upon impacting. The energy release characteristics of Ni-Al-W reactive material were analysed. The chemical energy and pressure generated by reaction of the reactive material have a linear relationship with the impact velocity. A warhead prototype of Ni-Al-W fragment warhead was designed and the warhead explosion testing was carried out. The results show that the Ni-Al-W fragments are capable of withstanding to explosive loading with acquiring initial velocity of 2256m/s. The Ni-Al-W fragments also have advantage of perforation in area against the bi-layered space plates. The metallic reactive fragment warhead can increase the lethality of fragmentation warheads against aircrafts and phased array antenna, which increasingly get mature and have a wide application prospect.

## 1. Introduction

In recent years, reactive fragments are developed as means to increase the lethality of direct-hit or fragmentation warheads [1-3]. Reactive fragments consist of a class of energetic materials, characterized by ignition upon impact and release of chemical energy. Especially, the reactive fragments of polymer/metal such as PTFE/Al received broad attention because of their high chemical energy and special response to mechanical shock. But owing to their lack of structural rigidity and strength, they need to be protected by inert metal case such as steel as to withstand explosive loading, which limits their broad using and lethality performance.

Metallic reactive materials or so called structural energetic materials, are made of two or more kinds of metal powders, and metal alloying reactions and oxidation reactions occur under high-speed impact, releasing chemical energy and causing damage effects. A good review of the field was published by Eakins and Thadhani [4]. The applications of structural energetic materials require us to study their dynamic response behavior under explosive loading and assess damage effects on targets. The fragmentation behavior and reactions of binary intermetallic compounds has been studied for several cases of materials [5-8], but few studies of a ternary intermetallic compounds composed of



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nickel-aluminum-tungsten formed via hot isostatic pressing have been conducted to investigate the dynamic mechanical behavior under explosive loading.

In the present work, composition, structure, manufacturing process and properties of Metallic reactive materials are introduced. This paper deals with a ternary mixture of Ni-Al-W and the reactive materials refers to Ni-Al-W materials later if not stated. The static and dynamic mechanical performance of Ni-Al-W materials were tested and the energy release characteristics were analyzed. A warhead prototype of Ni-Al-W fragment warhead was design and the warhead explosion testing was carried out. The dynamic response behavior of the Ni-Al-W structural energetic material under explosive loading and damage effects on bi-layered space target are analyzed. Fragments recover analysis and high-speed camera images were used to provide insight into the deformation and fragmentation process under explosive loading and subsequent reaction behavior of the Ni-Al-W fragments.

## 2. Material & properties

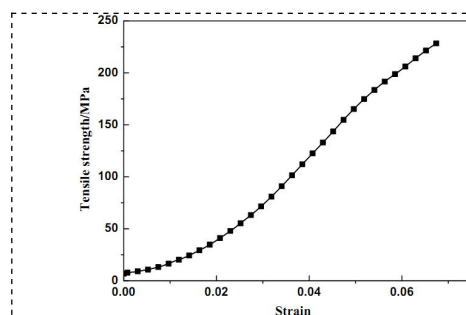
### 2.1. Formulation and processing technology

The metallic reactive materials are all metal-metal mixture systems, which may consist of two or more kinds of the following metal powders W, Ni, Ta, Al, Zr etc. Processing technology is generally powder metallurgy. It notes that temperature should be controlled strictly during the manufacturing process to prevent reactions to form intermetallics and liberate energy.

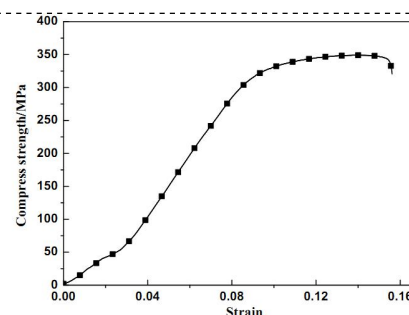
The average particle sizes of Al powder, Ni powder, and W powder were 20 $\mu\text{m}$ , 25 $\mu\text{m}$ , and 5 $\mu\text{m}$ . And their volume fractions are 56%, 20% and 24% respectively. Then we obtain blank by slowly pressurizing to 500 MPa by hydraulic press and holding pressure for 2~3min. Put it in a vacuum tube furnace and raise the temperature to 500°C at a heating rate of 10°C/min. After isothermal for 1h, cool it to room temperature with the furnace to obtain a reactive material with a certain strength. The density of the material measured by the drainage method was 7.37 g/cm<sup>3</sup>. Besides by hot isostatic pressing, the density of Ni-Al-W reaches 7.52g/cm<sup>3</sup>.

### 2.2. Mechanical performance

The typical tensile and compress samples were machined to form GB 16421-1996 type I samples. The testing rate was 10 mm/min and all the samples were strained to failure. Strain data were obtained by using strain gauges. The tensile and compressing stress-strain curves of Ni-Al-W samples are displayed in figure 1 and figure 2 respectively.

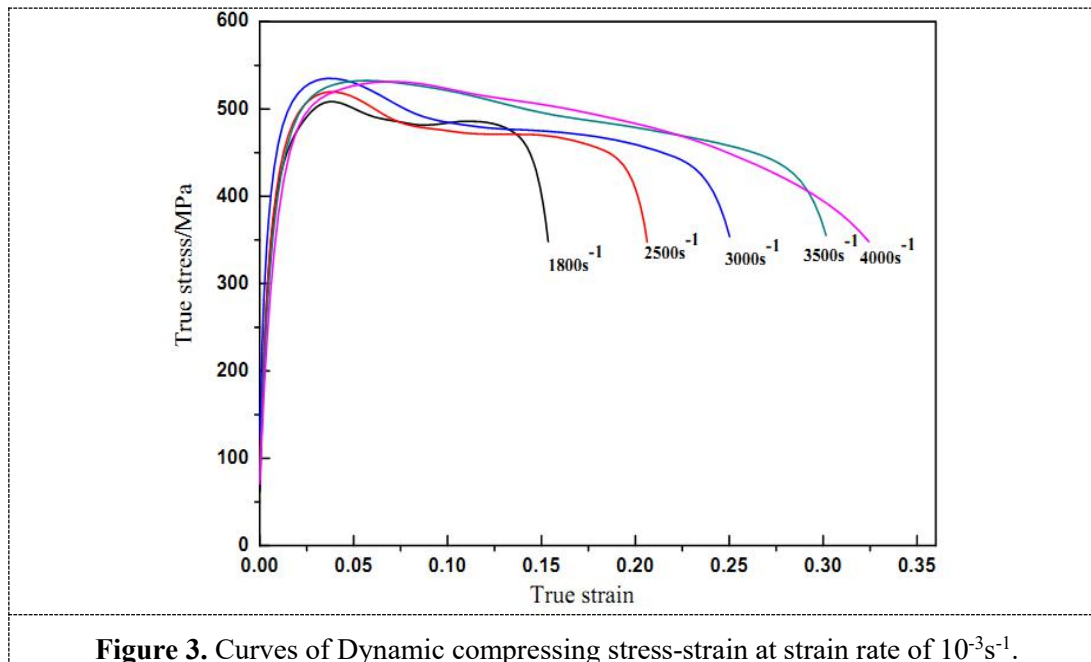


**Figure 1.** Stress-strain curve of static tensile test.



**Figure 2.** Stress-strain curve of static compressing test.

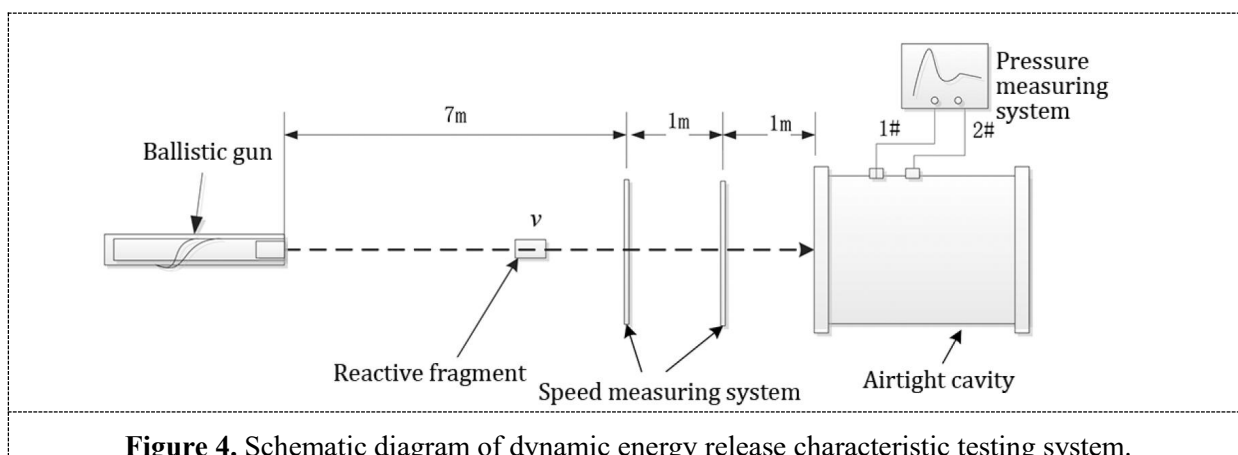
As shown in figure 1 and figure 2, the tensile strength is 228MPa and the compressing strength is 349MPa under quasi-static loading.



The stress-strain curve of Ni-Al-W material under dynamic compression with a strain rate of  $10^3 \text{ s}^{-1}$  is shown in figure3. The dynamic compression strength is about 500MPa at strain rate of 1800 ~ 4000 $\text{s}^{-1}$  by split Hopkinson pressure bar testing. As shown in figure1, Ni-Al-W material have no effect of strain hardening and strain rate hardening under dynamic compression at strain rate of 1800 ~ 4000 $\text{s}^{-1}$ , but with the increase of the loading strain rate, its thermal softening effect is significant.

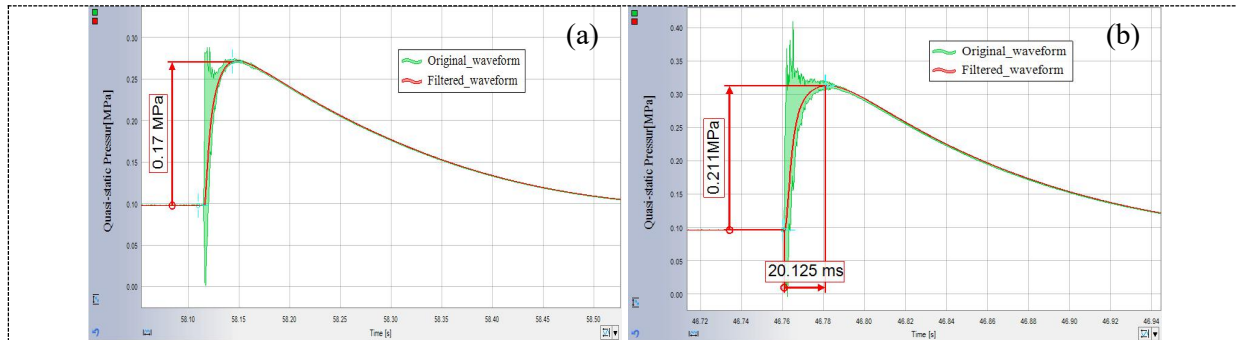
### 2.3. Dynamic energy release characteristic

To characterize the performance of reactive fragments, a vented chamber calorimetry is introduced and the corresponding test setup is designed. As shown in figure4, the test setup mainly consists of an initial closed chamber, ballistic guns, and speed measuring devices. The initial closed chamber has a diameter of 0.3m, a length of 0.38m. There is a harden anvil (20mm thick 45# steel) with a on the interior, two symmetrical optical inspection hole and some pressure gauges embedded in the side wall of the chamber. The test chamber is covered and sealed with a 3 mm thick 2A12 aluminum plate and the volume of the chamber is  $27 \times 10^{-3} \text{ m}^3$ .



The Ni-Al-W reactive fragments with a mass of 10 g are launched by ballistics gun. figure5 are the pressure curves generated by the reactive fragments after penetrating the aluminum alloy plate and

hitting the anvil with speeds of 889m/s and 1046m/s respectively. After the reactive fragment begins to react, the pressure rises rapidly. As time passes, the pressure of the container gradually decreases due to thermal diffusion, perforation, etc., and the pressure peak time is 29.8 ms and 20.1 ms, respectively.



**Figure 5.** Pressure time trace of reactive fragment at (a)889m/s and (b)1046m/s.

The impact velocity of the reactive fragment greatly affects the pressure, and the higher the velocity, the greater the pressure. Relationship of pressure and velocity are shown in figure 6. The linear fit gives the velocity and pressure relationships as:

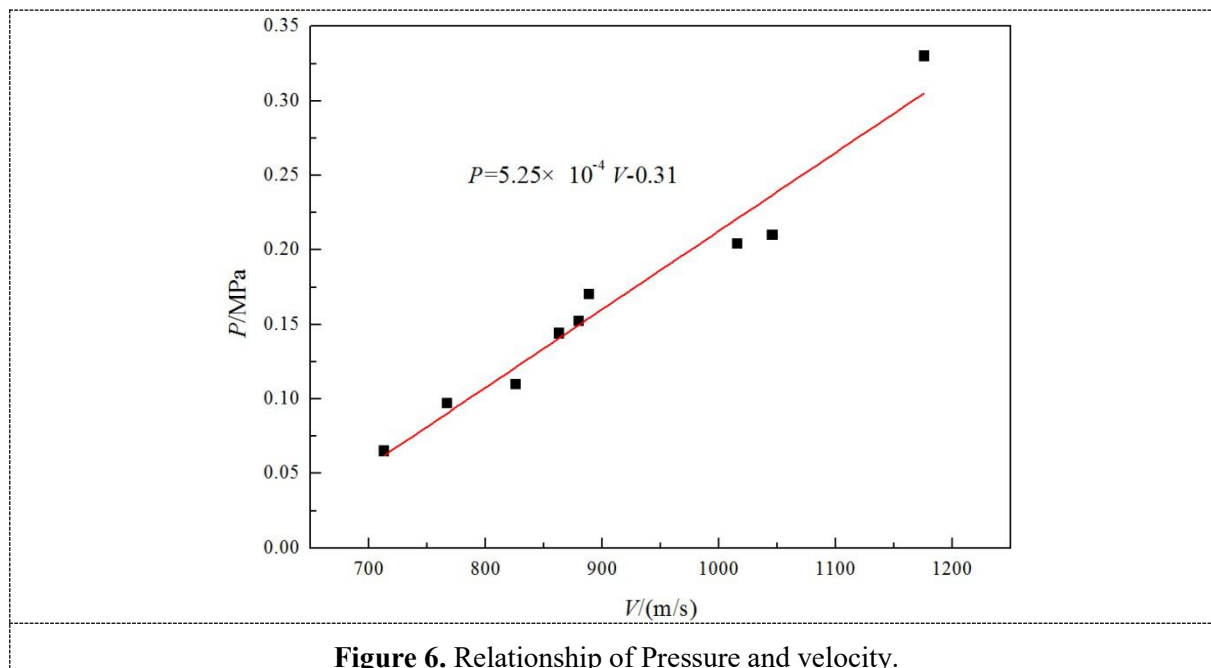
$$P = 5.25 \times 10^{-4} V - 0.31 \quad (1)$$

where  $P$  is pressure, MPa;  $V$  is impact velocity, m/s; fitting correlation coefficient is 0.9517.

From equation (1) and figure 6, it can be seen that the pressure has a linear relationship with speed in the speed range of 713 m/s to 1176 m/s. The higher impact velocity, the greater pressure is, which means that the reactive fragments release more chemical energy with the increase of speed. Irrespective of the kinetic energy of the fragment, the pressure can be related directly to the energy release using the following relation in reference [2]:

$$e = \frac{P \Delta V}{m(\gamma - 1)} \quad (2)$$

where  $e$  is the unit mass of the reactive fragment release chemical energy, J/g;  $P$  is the pressure in the container, MPa;  $\Delta V$  is the internal volume of the container;  $m$  is the mass of the reactive fragment, g;  $\gamma$  is the gas adiabatic constant,  $\gamma=1.4$  for air.



**Figure 6.** Relationship of Pressure and velocity.

According to equation (2) and figure 6, when the impact velocity is 1046m/s, the chemical energy released by the reactive fragment is 1.42kJ/g, and when the impact velocity is 1176m/s, the chemical energy released by the reactive fragment is 2.23kJ/g. The Ni-Al-W fragments undergo intermetallic reaction and oxidation reaction upon impacting, because the energy output is relatively high than that of intermetallic reaction.

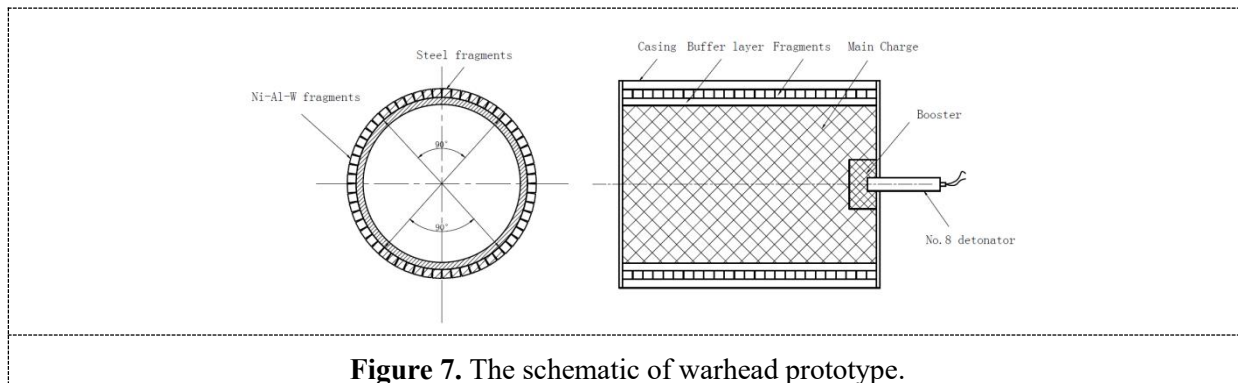
### 3. Applications

#### 3.1. Metallic reactive fragment application in anti-aircraft missile warhead

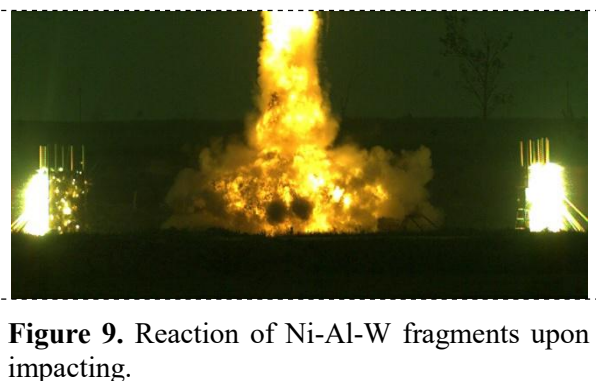
The damage effects of metallic reactive fragments warhead on aircraft simulation target was studied. The metallic reactive fragments warhead prototype is 340 mm long x 300 mm OD and the weight is about 50kg. As shown in figure7, the warhead employs two kinds of fragments, i.e Ni-Al-W fragments and steel fragments. The steel fragments were used as the reference to assess the damage enhancement effects of the Ni-Al-W fragments. The Ni-Al-W fragments and steel fragments were 10mm cubes and the weights of these were 7.4g and 7.8g respectively. The bi-layered space plates were used to evaluate the damage effect of the Ni-Al-W fragments, of which the front plate were 6mm thick steel plates and the end plates were 1.5mm thick aluminum plates, and the distance between the front plates and the end plates were 80mm. The bi-layered space plates with 4 m high by 5 m arc length for each region were located at a distance of 15 m from the warhead.

The initial velocities of Ni-Al-W fragments and steel fragments were 2256m/s and 2205m/s respectively. Thus both the impacting velocity of Ni-Al-W fragments and steel fragments away 15m from the center of the arena were nearly 1300 m/s.



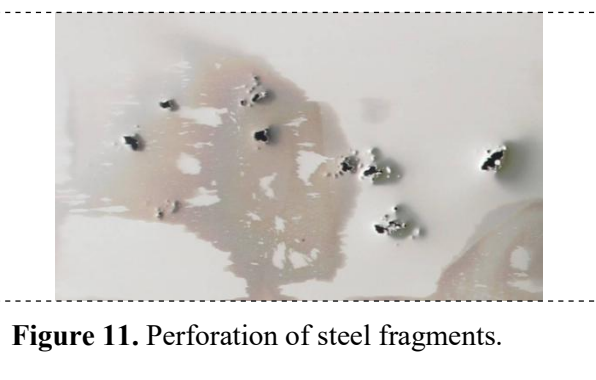
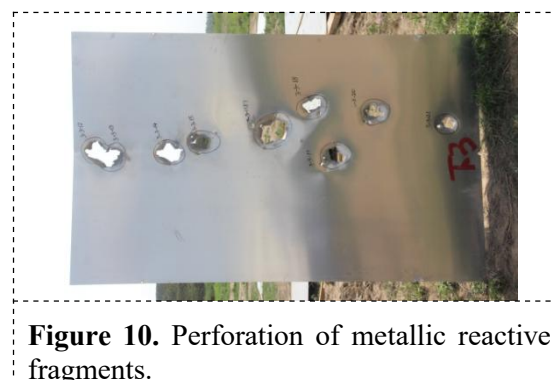


As shown in figure8, the Ni-Al-W fragments occurred some degree of deformation but remained continuous as a whole, but the weight loss of Ni-Al-W fragments is 8% by average.



The metallic reactive fragments impacted the steel plate and reacted violently to produce persistent dazzling flame for a long time. A typical picture of the moment when the amount of the Ni-Al-W fragments were impacting the bi-layered space plates and reacting is shown in figure9. As shown in figure9, the big flame and duration of 40ms indicate that the Ni-Al-W fragments react upon impacting violently.

Both the metallic reactive fragments and steel fragments penetrated the 6mm thick steel plates and perforated 1.5mm thick aluminum plates. The areas of hole perforated by the metallic reactive fragments are 4 times larger than of steel fragments. The holes perforated by the metallic reactive fragments and steel fragments are shown in figure10 and figure11.



The metallic reactive fragments have advantage of steel fragments in perforation area on account of low strength and reaction upon impacting. Compared to steel fragments, the metallic reactive

fragments are easier to break to generate debris cloud which were large than the origin fragments thus perforate the targets. Meanwhile the debris of the metallic reactive fragments reacted and produced overpressure to enlarge the holes.

The metallic reactive fragments have advantage of perforation, tearing destruction and other damage effects, which could be used to warhead to enhance the lethality of anti-aircraft missile warhead.

### 3.2. Metallic reactive fragment application in Anti-Radiation Missile warhead

The damage effect of metallic reactive fragment warhead on the simulated target of "Patriot" phased array radar antenna was studied. The antenna of "Patriot" AN/MPQ-53 phased array radar is the vulnerable part of the system. The antenna of phased array radar consists of antenna array unit, phase shifter unit, transmitter and receiver unit, wave controller unit, exciter unit, cooler unit and antenna support frame unit. The diameter of the antenna of main array radar is 2.44m and there are 5161 phase shifter units.

Based on the prototype of the warhead with the size of 330mm× 500mm and the mass of 100kg, the metallic reactive fragments with the mass of 9.4g were filled. The radar antenna simulation targets were placed at a distance of 15 m from the explosion center, with 8 modules and 1152 phase shifter units.

The initial velocities of metallic reactive fragments with a mass of 9.4g were 1800 m/s, and the instantaneous velocity is about 1200 m/s when they flew to 15 m away from the warhead. Twenty-two fragments hit the radar antenna simulation target, and 465 phase shifter units were damaged. The damage probability is 40%. One metallic reactive fragment may destroy 20 phase shifter units on average.

After penetrating the shield and substrate of the phased array radar antenna, the metallic reactive fragments produce fragments and overpressure, which destroy the phase shifter unit, as shown in figure12.

For the multi-layered plates (6 mm steel plate+1.5 mm aluminum plate), places at 15m away from the warhead, the damage effects such as hole enlargement and tearing are significant, as shown in figure13.



**Figure 12.** Damage effect on phased array radar antenna module.



**Figure 13.** Typical Damage effect on Aluminum sheet.

In conclusion, the metallic reactive fragments impacting on the targets may produce obvious hole reaming effect and overpressure damage effect, which can seriously destroy the phased array radar antenna and can be used as fragments of anti-radiation missile warhead.



#### 4. Conclusion

The method of cold pressing-sintering and hot isostatic pressing are suitable for material making. When the density of metallic reactive fragment is not less than  $7\text{g/cm}^3$ , the tensile strength is not less than 300MPa and the elongation is more than 5%, it can resist explosion loading and can be used as the fragment of warhead. It is suggested that the density of metallic reactive fragments should be increased to  $8\sim 10\text{g/cm}^3$ , the elongation is more than 7%, the adaptability is better and the application will be more extensive.

The typical ternary mixture of Ni-Al-W have high density of  $7.37\text{g/cm}^3$  and static tensile strength of 228MPa, which make the reactive fragments gain high penetration capability to perforate the target's skin and can survive under explosive loading. The Ni-Al-W fragments undergo intermetallic reaction and oxidation reaction upon impacting. As the impact speed increases, the release energy augments and damage effects enhance. In the protection of the lower wave impedance material buffer, the Ni-Al-W fragments can survive under explosive loading with acquiring initial velocity of 2256m/s.

The metallic reactive fragment warhead has obvious damage effects on aircraft targets and phased array radar antennas, such as hole enlargement and tearing, which can be applied to air defense and anti-missile missiles and anti-radiation missiles to improve their lethality performance.

The technology of metallic reactive fragments is becoming more and more mature and has a wide application prospect.

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