International Journal of Social Science Research and Review

http://ijssrr.com
editor@ijssrr.com
Volume 5, Issue 12
December, 2022
Pages: 287-296

Metal as a Ballistic-Resistant Lightweight Protective Material in the Military Field

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http://dx.doi.org/10.47814/ijssrr.v5i12.808

Abstract

The use of metal and composite materials in the military field is very wide. This review provides insight into metallic materials, metal composites and structures and their applications in defense, particularly as light weight ballistic shielding materials. In general, three categories—clothing, helmets, vehicles, and structure reinforcement—can be used to classify military needs that call for materials with strong ballistic resistance. Increasing the capability of metal and composite materials through reduced weight is proven to provide significant performance in increasing the mobility capabilities of personnel and vehicle defense.

Keywords: *Metal, Composite; Protective Material; Military; Defense*

Introduction

During the past 50 years, the most important thing in the military field has been an increase in the ability of armor materials to withstand projectile and ballistic impacts, as well as a reduction in the weight of a protective material. The weight of the protective materials needed for the protection of military troops and vehicles has greatly decreased because to the choice of new materials such polymers, polymer fibers, ceramics, and metals with lower densities (National Academy of Sciences National Research Council, 2011). Additionally, a variety of light armor systems are utilized in a variety of applications, including body armor systems, light armored vehicles, and aircraft. These systems offer defense against projectiles and bullets (Adams et al.,2004). Future combat systems will be geared towards increased firepower, exceptional personnel protection, as well as strategic mobility capabilities and tactical agility. Therefore, we need a material that is lighter and able to withstand ballistic impacts which will be applied to protective materials for personnel and armored vehicles (Technik, 2003). Figure 1 shows that there is a revolutionary reduction in the area density of vehicle shielding materials, from rolled homogeneous shields to complex composite systems. The curve shows that titanium, aluminum, and ceramics are new lightweight materials and have the potential to increase protective capabilities at lower weights per area per unit of time. The flat curve shows that despite the threat being more serious, it will be difficult to reduce the density of the protective material area (Fink,2000).

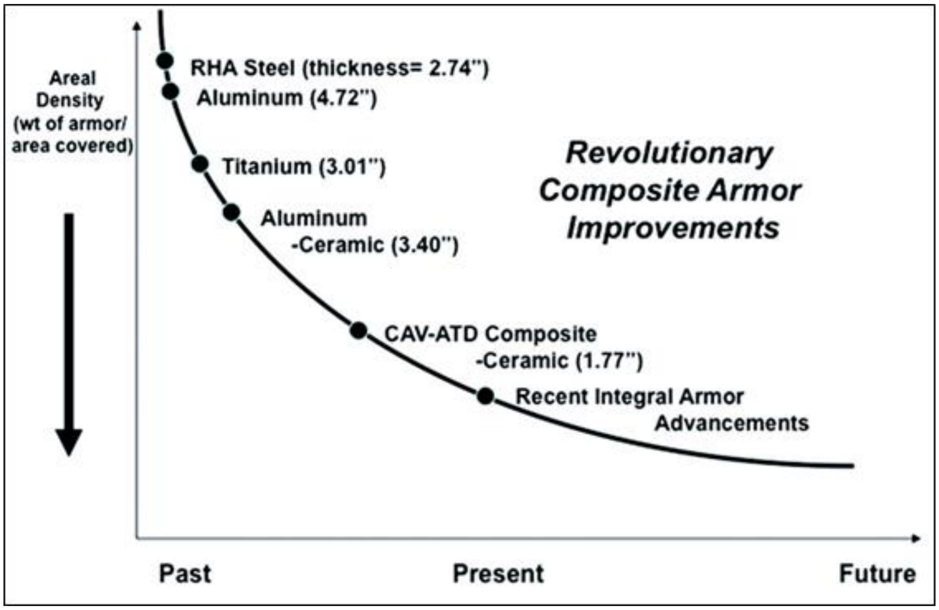

Figure 1. Area of protective material density against time (Source: Fink, B. K, 2000)

Metal Composite And Metal Matrix

For more than 2000 years, metal has become a protective material that has a very important role. One of them is steel, steel is an iron-based alloy. For most armies worldwide, steel has traditionally been the material of choice for protection. This is due to sophisticated steel technology at low cost and has a large base industry around the world. However, the problem is the use of steel used as a protective material by military personnel at this time is a very heavy material for protecting military personnel and vehicles, especially in the form of Rolled Homogeneous Armor (RHA). Therefore, it is crucial to produce light metals (not iron) to replace steel in order to meet military requirements. These substitutes grew more significant as military forces became more mechanized in the early 20th century. Global reach between nations depends on their capacity to swiftly deploy troops with mechanized armor characteristics in the current state of global security. This has pushed the use of lighter metals for people and armored vehicle protection as well as been a driving force in the development of lighter armored systems.

The majority of the protective material used for military vehicles today is made of metal, particularly metal in the form of a rolled-up steel and aluminum alloy. The reason for using metal is because metal is a relatively cheap material, more economical than other materials, easy to weld and can be used as a structural material as well as a protective material. In addition, metals also have a wide commercial market, a large industrial base and very low costs in terms of extraction, processing and processing. This makes metal material the best material to use as the main component of a protective system with a strong and inexpensive protective material orientation.

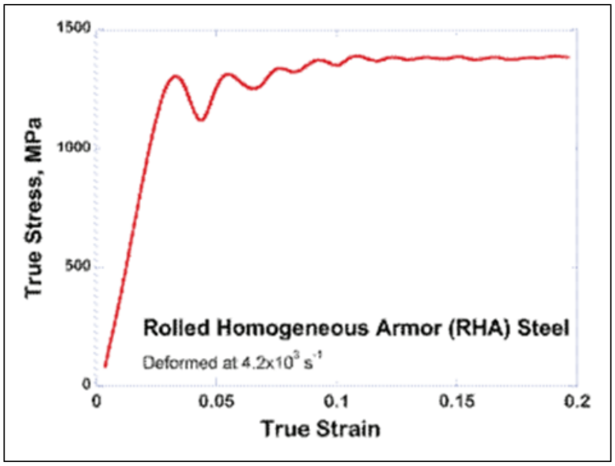

Figure 2. RHA steels' stress-strain profiles when compressed at high strain rates (Source: Zhang, H et.al, 2007)

The performance of RHA-based armor systems is measured in terms of specific threats and from the high stress-strain response depicted in figure 2 with regard to the assessment of the majority protective materials. Figure 2 illustrates the presence of a tiny but distinct strain hardening domain and a dynamic strength more than 1 GPa. Similar experiments are carried out over the temperature range, which gives an estimate of the thermal softening of the flow stress. The curve displaying the strain rate range will provide an estimate of the strain rate sensitivity of the flow stress. By converting the stated stresses and strains to comparable stresses and strains, one may roughly incorporate this constitutive behavior of metals like steel and aluminum alloys into the theory of flow-type plasticity. This means that these parameters, which include modulus, rate sensitivity, strain hardening, yield strength in uniaxial stress or compression, ultimate tensile strength in uniaxial stress, and failure strain in uniaxial tensile tests, will be able to determine the overall constitutive behavior of the metal at high strain rates.

Metal Material Attributes As A Protective Material

According to a number of articles (Wu Gaohui & Kuang Zeyang, 2022) metals have great strength, good ductility, a small amount of strain with hardening, and increasing strength with increasing deformation rate. Good formability so that the material can be formed into structures with suitable shapes and weldability for simple joining processes are additional required characteristics. Other required characteristics include good long-term performance in the operating environment, for example, corrosion resistance. The dynamic failure process, however, also has a significant impact on the performance of the protective material in the face of specific threats, in addition to the basic behavior of the protective material.

The growth of voids under mostly tensile conditions (Seaman, et al, 2003) and localization of adiabatic shear under stress conditions and superimposed shear conditions (Wright,2002) are the main causes of failure mechanisms of a material. A metal's spall resistance and sensitivity to adiabatic shear localization are essentially what determine how resistant it is to dynamic failure. An analysis that combines constitutive response with a method that considers the distribution of internal faults can effectively restrict the strength of metal spalls (at the lower end). The material's rate of thermal softening and the sensitivity of the strain rate determine how susceptible the material is to localization of adiabatic shear. In addition to methods that merely improve the initial yield strength, hardening and softening mechanisms in the material must be taken into account. As an illustration, a lot of high-strength metals have very low rate sensitivity, making them vulnerable to adiabatic shear localisation. Designing new metal protection materials requires a thorough understanding of the relationship between microstructure and failure mechanisms in metals because the significance of each of these failure mechanisms for a given material depends on the particular geometry of the shielding structure as well as the specific threat.

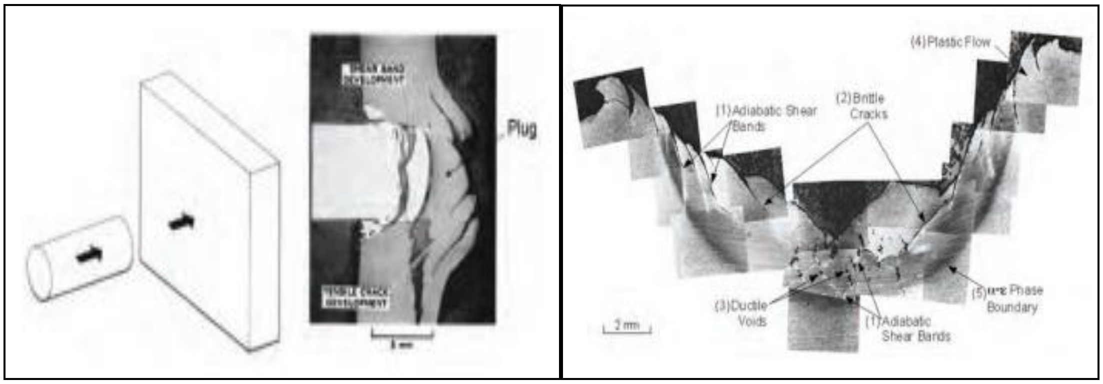

Figure 3. (a) Impact on a steel plate that is struck by an object, and (b) Five modes of damage to a steel plate when a 12.7 mm diameter polycarbonate ball strikes it at a speed of 6 km/s. (Source: Shockey, D.A., D.R. Curran, and P.S. De Carli, 1975)

In Figure 3. (a), As can be seen, microscopic failure processes in the plate and rod, such as shear bands, homogenous plastic flow, and tensile fractures, can predict how the rod and plate will interact. The nature of the plates and bars and the conditions of impact will determine which failure process operates. One, more than one, or all of the five failure modes—plastic deformation, adiabatic shear bands, fractures, voids, and phase changes—can contribute to ballistic penetration of metal. Figure 3. (b) shows a polished cross section carved through a crater in a steel plate that is 1 inch thick and being pounded at 6 km/s by a 12.7 mm-diameter polycarbonate ball (Shockey et al, 1975). The diabatic shear band can be seen as a white etching band made of unwrought hard martensite and extends to the plate(1), when viewed from the edge, the strain localization surface will look like a band. A brittle crack (2) that crosses over with other cracks and can release the fragments follows the band path. Just below the crater (3), there is a spherical hollow that is a result of shear bands connecting the ductile tensile failure. The horizontal variation of the rolling process line serves to define the homogeneous plastic flow (4). Last but not least, the dark etching material's hemispherical volume is slightly below the point at which stress causes a polymorphic phase transition (5).

By manipulating the microstructure using chemical and thermomechanical methods like as dispersoid deposition and hardening, solid solution hardening, and grain boundary strengthening, it is possible to significantly alter the mechanical characteristics of metals. Additionally, by increasing the number of internal dislocations by procedures like work hardening, many metals and metal alloys can be significantly strengthened. This is one benefit of using metallic materials—the processing required for metalworking is frequently tuned to raise the materials' ductility and strength. Rolling is an effective work-hardening technique and is frequently used to create plate shapes. In actuality, rolled metal may be significantly more robust than unrolled metal.

Nonferrous Metal Alternative

1. Titanium And Titanium Alloy

Titanium is a hexagonally packed metal with a density of 4950 kg/m3. Due to its high strength-to-weight ratio, superior corrosion resistance, and superior ballistic performance when compared to steel and aluminum alloys, titanium has several advantages (Madhu et al, 2011). Titanium has weaknesses, one of which is the formation of adiabatic shear bands that can cause spalling (Bhat et al, 2005). Although titanium has been used successfully in the manufacture of aircraft for many years, the expensive cost of the material as well as the lack of knowledge about its ballistic characteristics restrict its widespread usage in the manufacture of ground vehicles. Early in the 1950s, Pitler and Hulich (Pitler et al, 1950) noticed that titanium had the potential to serve as a structural screen against small-arm projectiles. Extra low interstitial grad (ELI) and the alloy Ti-6Al-4V were the materials of choice for armor applications in 1964. The ballistic performance of the Ti-6Al-4V alloy on the kinetic energy (KE) of projectiles has been investigated (Gooch et al, 1996). Tungsten alloy (WA) projectiles 7.25 mm or 7.8 mm in diameter and 78 mm and 145 mm in length yield a length/diameter (L/D) ratio of 10 to 20. Low density, hardness and high strength at a wide range of thicknesses The plate is referred to as a unique material and the mechanical properties of titanium alloys have resulted in an excellent ballistic material for armor design. Cost is the greatest barrier to the spread of titanium use. Because titanium is extracted, processed, and shaped to produce finished products that are far more expensive than steel components, this barrier to growth is very significant. Second, titanium's alloying factor is susceptible to adiabatic shear localisation to a reasonably high degree, like many other hexagonal solid metals. Due to these reasons, the use of aluminum and aluminum alloys has increased in place of steel.

2. Aluminum And Aluminum Alloy

The development of aluminum and aluminum alloys began in the early twentieth century and was applied during World War II. In the late 1950s, the transportation of personnel with T113N and M113 materials using an aluminum alloy structure led to the development and application of large quantities of aluminum alloys to armored fleets. In these applications, weldable aluminum alloys are preferred and so widely used that many have to pay a penalty in terms of strength and ballistic performance. The interchangeability of weight, ease of production, ballistic performance, and ease of maintenance, particularly corrosion resistance, play a critical role in choosing alloys for vehicle defense applications. The majority of these alloys are employed as rolled plates, particularly work-hardening alloys from the 5000 family (Al 5083 is a notable example). Additionally, Al 2024, Al 2519, Al 5059, Al 6061, Al 7039, and Al 7075 are aluminum alloys that are employed as armor in Army vehicles. Al 2139, a commercial alloy with respectable ductility and strong strength (about 600 MPa at high strain rate), is one of the more promising new commercial alloys. Through alloying techniques, the creation of nanostructured systems, and the creation of aluminum-based composites, there is considerable potential for the development of novel materials with an extraordinarily high strength. The trimodal aluminum material serves as an example of the nanostructured aluminum strategy. When loaded at high strain rates, this aluminum-based material displays extremely high strength between 950 and 1,000 MPa.

3. Magnesium and Magnesium Alloy

Aluminum has a density of 2800 kg/m3, titanium has a density of 4950 kg/m3, steel has a density of 7800 kg/m3, and magnesium has a very low density of approximately 1700 kg/m3. It is well known that magnesium has a density that is comparable to polymers. Due to their high relevance in the tooling and automotive sectors, magnesium and its alloys are among the lightest structural metals. Due to its low density, this material is highly desirable for use in military applications, however historically, magnesium alloys have only had relatively modest strengths of between 250 and 300 Mpa. Over the past ten years, significant attempts have been made to develop high-strength magnesium alloys utilizing a number of techniques, such as precipitation strengthening and solid solution strengthening. Commercial magnesium alloys like AZ315 and ZK60, as well as other alloys containing rare earth elements, may be able to replace some aluminum alloys. The production of fine-grained or nanostructured magnesium alloys via plastic deformation is one of the more promising reinforcement techniques. The potential afforded by these magnesium alloys should not be passed up since research on magnesium alloys is so promising that significant research is required to establish a fundamental understanding of the strengthening mechanisms in magnesium alloys. Magnesium has a far more complex plastic deformation than cubic metals like aluminum and steel because it is a densely hexagonally packed substance. The emergence of deformation twinning and the emergence of robust textures are two key characteristics of plastic deformation. To make magnesium-based materials more usable as components of protective material systems, these areas need to be carefully investigated.

4. CERMET (Metal Ceramic Composite)

A construction that is a composite blend of a metal phase and a ceramic phase is referred to as "cermet." The cermet's ceramic and metal composition enhances the composite material's toughness in a synergistic way: The ductile metal phase prevents failure, while the ceramic phase is the strengthening phase with the job of breaking the penetrator. Aluminum, magnesium, and titanium are the most frequently used metals (Lloyd, 1994). Cermets can be split into two subgroups: ceramic-matrix composites and metal-matrix composites, depending on whether the ceramic is in a continuous phase or a matrix phase (MMC). The cermet material has good ballistic qualities and is lightweight, making it ideal for use in personal protective gear. Cermets have not, however, been utilized extensively in armor protection applications due to a number of factors, including expensive manufacturing costs, a lack of understanding of bonding and cermet characteristics, and a failure to completely realize optimal composite qualities. A MMC micrograph with the SiC phase distributed in an aluminum matrix is shown in Figure 4.

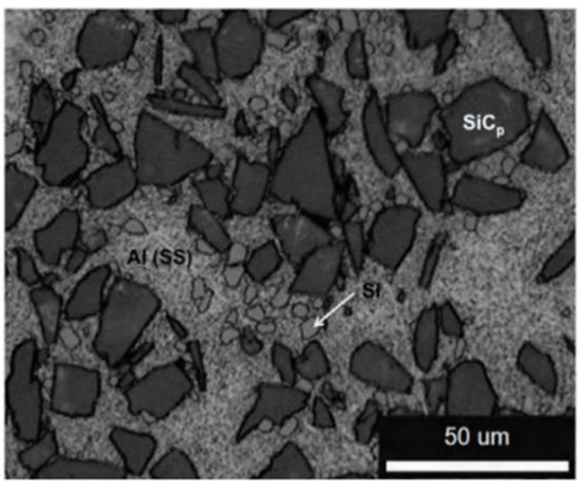

Figure 4. Al-SiC optical micrograph in Cermet. The aluminum has discrete silicon carbide particles and a light gray matrix hue. (Source: KT Ramesh).

Utilizing a combination of typical refractory ceramic materials (alumina/Al2O3, silicon carbide/SiC, and boron carbide/B4C) and light metals like magnesium, titanium, and aluminum, one can easily exploit the protective substance of cermets. Due to their toughness and impact resistance, cermets have been employed successfully in armor protection applications; however, the best qualities of each component phase are frequently not fully integrated in composite structures. Cermets are reasonably simple to fabricate and come in a wide range of forms, however the majority of MMCs, like aluminum, were created using metallic phases with relatively low melting temperatures. Special fabrication methods are needed for components that operate at higher temperatures. It is possible to conduct fruitful study into the mechanisms underlying high temperature metal-ceramic bonding in cermets, the creation of these structures, and their connection to projectile deflection and shielding effectiveness.

Research Method

The research was conducted using a qualitative, descriptive analytic method. Understanding and examining the meaning of a person or group of people is done through qualitative research, which might be influenced by current social or humanitarian issues (Creswell, 2014). Data collection in this article using library research techniques, namely: is a literature with studies that related to values, norms and culture that is being socially in data collection using material in books, letters online news, journals, articles and documents others relevant to the topic of the article (Creswell, 2018). According to Creswell (2018), literature study is a series of conscious effort and sustainable with data collection, reading multiple sources, taking notes some important things and managed so that it becomes a complete data in a study. Write that literature study is the way researchers in get data sourced from literature read and some sources relevant such as books, journals, scientific articles and others. Research is intended to analyze data using literature study method as a basis in explore about the topic.

Result and Discussion

In the military, qualified personnel and equipment are needed to be able to protect themselves from all forms of threats. Some of the equipment needed by military personnel are military uniforms, military shoes, troop helmets, anti-CBRNE pilot helmets, night vision goggles (NVG), gloves, and survival equipment. Body armor clothes, fire-resistant camouflage clothing, explosion-proof blankets, and explosive ordenance disposal (EOD) clothing are examples of standard military outfits. Meta-aramid fiber, polyimide, sulfone aramid fiber, polyarylate fiber, polyarylene oxadiazole fiber, polyether ketone fiber, polyamide-imide fiber, and polyparaphenylene benzobisoxazole fiber are examples of intrinsic refractory fibers. The type of threat and level of protection required is the major determinant in body armor design. Fibers made of polyamide and very high molecular weight polyethylene have been created for applications requiring ballistic resistance as polymer science improves. This construction offers significantly more protection per unit weight of material and offers greater comfort. In the manufacture of military shoes, several materials that can be used as composite materials for military shoe soles are Trimethyldihydroquinoline (TMQ) (Antidegradant), Dry Natural Rubber (NR) Acid (Co-activator), Zinc Oxide (Co-activator), Stearic Acid, Benzothiazole disulfide (MBTS) (Accelerator), Sulfur (Curing Agent).

Military personnel that use ballistic helmets do so because these helmets provide higher protection while being lightweight and strong thanks to materials like Kevlar and Aramid. A fiber-reinforced polymer matrix composite, commercialized under the trade names "Kevlar®" and "Nomex®," is the material used to make helmets. The polymer matrix is comprised of nylon, a thermoset resin, and the fibers are aramid, an aromatic polyimide resin invented by EI duPont de Nemours and Company. With research and development carried out by the American military, military helmets made entirely of composites were introduced in the early 1980s. The helmet is made up of aramid fabric prepregs and its ballistic performance is doubled compared to helmets made of steel. The performance of helmets has improved while helmet weight has decreased by up to 20% thanks to the introduction of HMPE materials and fibers. The use of nonwoven technology combined with all ballistic fibers results in a 10% weight reduction for helmets while maintaining performance.

A night vision device (NVD) is an electro-optic device that improves vision in environments with little or no light. With night vision, we can see a person standing more than 200 m away at night. Night vision uses infrared light as well as conventional detection called thermal imaging, the resulting form is usually monochrome, for example shades of green. At this time night vision is divided into two types, namely image intensification and image enhancement. Night vision with image intensification technology, can be analogous to a megaphone, or loudspeaker or commonly called a toa. From a weak sound, after passing through the instrument, it then came out into a louder sound. Likewise in night vision, very dim light entering the night vision device will be amplified many times so that it looks brighter.

Current military protective gear systems rely on a variety of polymer composite materials to provide good ballistic protection. The use of composite materials in the production of military equipment makes military equipment lighter so that it can increase the mobility of military personnel and military vehicles. Military vehicles made using fiber-reinforced composite materials can reduce vehicle weight, increase mobility, increase fuel efficiency and increase vehicle life. The composite used is a spall liner. Spall liner is the general name for a soft material, which is usually made of aramid fiber laminate, glass fiber, or high density polyethylene (HDPE), which is installed in the crew compartment of vehicles, coating the interior surfaces of tanks, combat vehicles and personnel carriers that serves as a type of protection. interiors. Spall liner serves to prevent fragments (spall) generated during warfare from hitting military personnel. Spall liners can be used as additional protection if the armor system is overmatched (a term used when an incoming projectile has more penetrating power than the armor stopping power (Mardiyati, 2018).

Conclusion

1 Metallic materials will be an essential part of future protective material systems due to the metal's excellent performance, i.e. ease of fabrication and joining, and a strong industrial basis.
2 Titanium alloys offer good protective capacity, but the metallurgical mechanism during penetration is not fully understood. The main obstacles to increasing the use of titanium as a protective material are its relatively high susceptibility to adiabatic shear localization and the high cost of titanium's extraction, processing, and shaping, which all lead to final components that are much more expensive than those made of steel and titanium alloys.
3 The development of new, enhanced aluminum alloys that can take the place of steel in military vehicles has a lot of potential. In the future, efforts to improve the ductility and strength of aluminum alloys under high strain rates are likely to be very beneficial.
4 Due to magnesium's extremely low density, highly lightweight substitutes for conventional metallic materials in protective material systems may one day be developed. It is important to get a fundamental understanding of magnesium's strengthening mechanism, particularly how fine-grained magnesium alloys are created by plastic deformation. Additionally, magnesium-based fiber deserves further investigation.
5 Cermets have been effectively used in applications requiring armor protection because of their toughness and impact resistance. A metallic phase with a relatively low melting point was used in the development of the majority of MMCs, including aluminum. Additionally, cermet materials have great ballistic qualities and are lightweight, making them appropriate for use as personnel protective materials.

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