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The research on transparent armor material technology

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The research on transparent armor material technology

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Abstract. Transparent armor is a kind of protective material integrating of structure and function, which has high transparency and high physical-chemical properties. It is widely used in ground vehicles, air platforms, personnel protective masks and other equipments. As a kind of highly strategic protective material, the new transparent armor with light weight, high transparency and high protection factor has a broad application prospect. The paper focuses on the research progress of new transparent armor materials at home and abroad, compares the current situation, analyzes the difference and puts forward some insights.

1. Introduction

In the modern action of asymmetric war, transparent armor has become essential and crucial for army and the air vehicles. Military vehicles of the western army have been equipped with transparent armor. Transparent armor can be key materials for the military helicopter and aerial platform combat. Traditional transparent armor generally uses the composite structure of multilayer organic glass, this kind of transparent armor has not only large thickness but also the high surface density. Meanwhile the protection performance is poor. Increasing the thickness and layers of armor in order to improve the protection performance leads to poor equipment maneuverability and optical distortion, which may decrease the optical properties [1-4]. These armor cannot satisfy the needs of modern war, and the development of new transparent armor with lighter quality and higher protection performance has been critical for increasing equipment mobility and combat capability.

Currently the research on new transparent armor has been carried out in America, France, Germany, Japan, Italy and other counties [2]. The new transparent ceramic composite armor such as sapphire, AlON, magnesium-alumina spinel and other composite armor have been developed to instead of transparent glass armor, in order to satisfy the requirements for modern weapons [1]. In this paper the research status of such kinds of new transparent armor has been reported and the gap analysis at home and abroad has been discussed.

2. The foreign status of transparent armor

2.1. Traditional transparent armor

The traditional transparent armor was composed of multiple layers of organic or inorganic glass, which was combined with bonding layer [2]. The increased thickness or layers has been used as the common methods to obtain higher protective capacity. Transparent armor was first used in the 1940s with multiple layers of glass panels for protection. In the 1970s, polycarbonate was investigated for use in transparent armor, and it was found to have a good blocking effect on glass fragments, effectively preventing them from entering the cockpit, therefore it had a good protection effect [3]. The Schott Company used borosilicate glass material to prepare a series of transparent armor products of Resistan. The protection level covers from 1 to 4 level satisfied NATO standards, and the weight of Resistan can be reduced by 12%~15% compared with ordinary natrium-calcium glass. The Isoclima Company of Italy researched transparent armor in the early 1980s, the company has been engaged in optimizing the composite structure of glass and polycarbonate material and developing suitable ceramic materials of lightweight, such as AlON, spinel and other new materials, in order to improve the mobility and keep the protection performance [5].

2.2. The new transparent armor

Due to the high weight of traditional transparent armor materials, a series of problems has been caused by increasing the thickness: (a) the increasing weight of the vehicle; (b) reduction of vehicle accommodation space; (c) decrease of optical capacity [6]. More studies have shown that the glass transparent armor has become inadequate in size, weight, transparency and optical distortion, and its limitations have seriously restricted the application and development of transparent armor. Therefore, new materials with high protective properties, small optical distortion, low density, high mechanical properties and low cost have become the focus of research and development [6].

Transparent ceramics, first proposed by General Electric in 1959, later were confirmed by R. L. Coble [7] with the prepared transparent alumina ceramics. Therefore transparent ceramic material was gradually applied in optics technology, high temperature technology, laser technology and special equipment manufacturing fields because of a good mechanical, optical, thermal, electrical and other performance. Meanwhile it has been used as a new material of choice for transparent armor [8].

2.2.1. Sapphire transparent armor. Sapphire was the most mature of the transparent ceramic materials, and had achieved industrialization. It had broad application prospects in armor protection, electromagnetic windows and semiconductor industries. Saint-Gobain expanded the size of sapphire crystals to 13 inches or more. In addition, Saint-Gobain had successfully reduced the cost by using edge growth technology to obtain transparent sapphire which was larger than 15 inches in size. However, the production cost increased due to the expansion of size. In addition, with the increase of sapphire size, polishing became more difficult, which meant the increase of polishing cost. This might limit the application of sapphire in transparent armor [9-10].

2.2.2. AlON transparent armor. In recent years, researchers found AlON transparent ceramics had excellent optical transmittance, high mechanical properties, high temperature resistance and thermal shock resistance. Comparable to sapphire, AlON transparent ceramics were easier to prepare large-size components than single-crystal sapphire as a polycrystalline material. Therefore AlON transparent ceramics could be used in windows, fairing, armor and infrared detection. Near-net size products with adjustable shape and size could be obtained by traditional molding process [11-12]. Yamaguchi first proved γ-AlON was a spinel structure which was stable above 1000°C in 1946. By the 1960s, French researchers had studied the phase components of AlON materials and the preparation process, then researchers also carried out mass studies of phase diagrams. The practical research on AlON transparent ceramics was mainly used in military industry, which greatly promoted the industrialization progress of AlON. Subsequently, many countries especially the United States, did a lot of research on AlON materials and broadened thei application of AlON. Now AlON had been listed as one of the most important transparent materials in the 21st century [13].

Raytheon conducted in-depth research on AlON ceramics under the military funding. In 2002, Raytheon transferred the full set of technology of preparing AlON transparent ceramics to Surmet, then Surmet started the commercial production of AlON and further improved the quality of AlON. Now the preparation of AlON powders has been mature for Surmet, and industrialization had been achieved. Surmet had been able to produce 70kg AlON transparent armor sized of 46x24x12.5 inch. Under the funding of military, Surmet conducted ballistic performance on AlON transparent ceramics, and the results showed that the ballistic performance of AlON was significantly better than traditional transparent armor. Meanwhile, under the same protective effect, the thickness of the new transparent ceramic armor of AlON was only one third of traditional transparent armor [14-15].

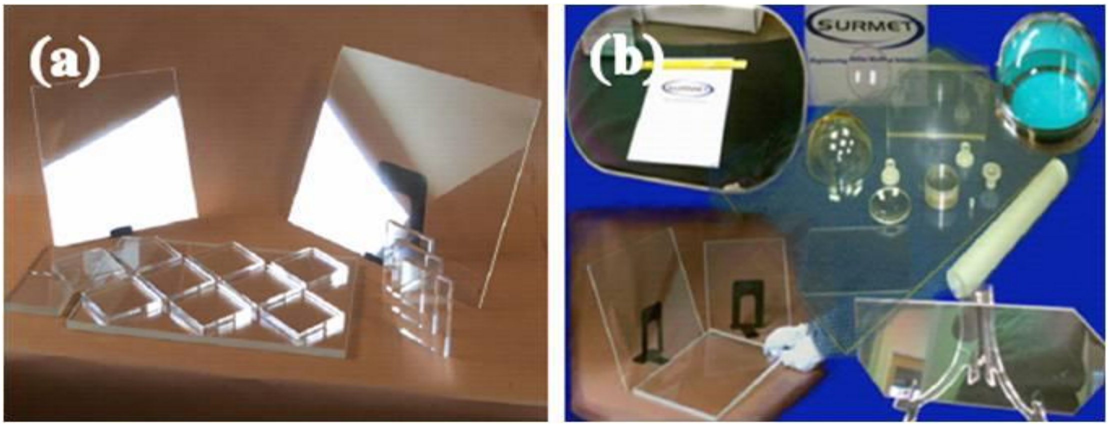

Figure 1. AlON of Surmet.

2.2.3. Other transparent armor. In addition, magnesium-alumina spinel ceramics were also a kind of polycrystalline transparent ceramics with good performance except the lower mechanical properties. In addition, magnesium-alumina spinel had more processing advantages than AlON. Meanwhile, magnesium-alumina spinel could be obtained by lower sintering temperature with lower cost. The magnesium-aluminum spinel had been proved a better optical performance, whose infrared wavelength was 6μm, while the AlON and sapphire were 5.5μm and 6μm respectively. Although the preparation of magnesium-aluminum spinel powder has been commercialized, the optical and physical properties of spinel can be improved by using HIP technology. However, it was still in the research and magnesium-aluminum spinel ceramics could not be used as transparent armor [16].

2.3. The discussion and summary

In contrast, sapphire transparent armor material had a non-cubic crystal structure and was currently manufactured and used only as a single crystal, while AlON and magnesium-alumina spinel can be used as polycrystalline materials. Sapphire is the most mature transparent ceramics currently, and achieved industrialization, but the higher cost limited its application because of the higher processing temperature and elaborate processing. Spinel powder can be purchased from commercial suppliers and its synthesis was relatively simple, but the preparation of the transparent ceramics was immature. However, the preparation of AlON, whether powder or ceramics, had achieved industrialization (Surmet's patents). AlON was better than single crystal sapphire both in cost and comprehensive performance. Moreover, for AlON and magnesium-alumina spinel, the damage effect to the projectile is obviously better than sapphire under the same test conditions in the study of Krell and Strassburger. It had been shown that larger and harder ceramic shards could better erode and destroy the projectile, resulting in effective wear and damage of the bullet. AlON and magnesium-alumina spinel had the larger ceramic shards compared to sapphire under the same test conditions. Therefore AlON and magnesium-alumina spinel ceramics had relatively higher ballistic performance than sapphire. Now, the United States had adopted AlON as a strategic defense material due to its comparative advantages. AlON had been used as a window material for ground vehicles and aircrafts.

3. The domestic status of transparent armor

In recent years, the research of AlON materials had been promoted duo to the advantages in various aspects in China. Sichuan University, Shanghai University, Shanghai Institute of Ceramics and No.52 Institute of China North Industries Group explored the development of preparation for AlON transparent ceramics. In addition, domestic researchers synthesized AlON powders by solid reaction method and carbothermal reduction and nitridation process, which was still at the stage of laboratory research and not industrialized.

4. The gap analysis and suggestions

There was a wide difference in the preparation of AlON transparent ceramics in China, compared to other countries. It could been concluded as follows:

(1) Difficulties in powder industrialization. Domestic powder preparation technology was immature, because of the late starting in AlON research and inadequate experience. Secondly, less investment and backward equipments which could not satisfy the actual demands contributed to the unstable powder quality and lower synthesis levels for the powders' industrialization. Therefore, the optimum facility which might satisfy the preparation demands needed more investments and the researchers had to lucubrate the development of preparation process in order to achieve the industrialization.

(2) Difficulties in preparing ceramics with lager size. Preparation process of transparent ceramics with small size was relatively mature, but the preparation of transparent ceramics with large size lacked of in-depth research. Molding process and facilities could not satisfy the actual demands. Meanwhile the sufficient and stable powders were essential to obtain the ceramics with larger size. Therefore, how to solve the difficulties in powder industrialization were necessary for preparing ceramics with larger size. In addition, adequate investments and development of molding process to obtain the green bodies with near net-shape and fewer defects were equally important.

(3) Difficulties in post-treatment of prepared ceramics. Due to the current technology, the post-treatment of transparent ceramics needed to use HIP equipment to further improve the density and comprehensive performance. However, less domestic HIP equipment could reach the requirements of size and function. Meanwhile the high temperature and pressure leaded to higher cost.

(4) Less research on numerical simulation of ballistic performance. Researchers frequently engaged in testing ballistic performance, and the systematic numerical simulation were ignored. Excessive dependence on ballistic performance test led to the single and unsystematic studies duo to the lack of samples. Therefore the numerical simulation should be combined with the ballistic performance test, and systematic studies should be carried out.

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