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## Research status and development of explosive welded metal materials

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# Research status and development of explosive welded metal materials

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**Abstract.** Explosive welding composites have been widely used in aerospace, petroleum, chemical, military and other fields, because of their characteristics of corrosion resistance, heat resistance and high strength. The theoretical research of metal explosive welded materials was introduced systematically, and the significance and trends of interface research were analyzed in this paper. Finally, the development trend of explosive welding of metal materials is prospected. It is pointed out that the prediction of damage behavior of explosive welding composites in service environment has certain scientific significance and engineering application value.

## 1. Introduction

Explosive welding is a solid-phase welding method. It uses explosive detonation to make the welding surface collide at an extremely high speed at a certain angle, resulting in severe plastic deformation at the interface and welding them together.

Explosive welding began in 1944 and was proposed by the American engineer Carl.L.R. In 1957, Phillipchuk successfully used explosion welding technology to realize the steel-aluminum connection and it's the first time that explosive welding has applied to actual production. Since then, many countries have started the research on explosive welding technology, making this technology gradually mature. Explosive welding was used early in the remote welding field or in place of conventional welding methods and is now used in production conductive bus transition joints, heat exchanger tubes and tube plate welding and it has been widely used in nuclear energy, aerospace, electronics, chemical industry, shipbuilding and other industries.

## 2. Explosion welding mechanism

Explosive welding technology has been experienced for more than 70 years since its appearance. Its theoretical research mainly focuses on the welding mechanism and the wave forming mechanism. With the popularization of computers and the application of simulation software, people usually use SPH, MPM, ALE and other models to simulate explosive welding under software platforms such as ANSYS, AUTODYN, and C++ to further reveal the explosion welding mechanism.



### *2.1. Welding mechanism*

At present, explosive welding is usually considered as a type of pressure welding. In the early days, Zernow, Davenport, Duvall, and Phillipchuck proposed that explosive welding is a fusion welding process. It is believed that the kinetic energy of a high-speed metal jet provides sufficient thermal energy for the melting the interface metal to melt and achieve welding. Liu Yucun [1] analyzed the explosion-welded A3 steel/copper samples and considered that explosive welding has the characteristics of fusion welding, pressure welding, and diffusion welding and jet flow. According to the literature, the high-speed pulse load acting on the cladding plate caused by the explosion causes the cladding plates have a high impact velocity. After the cladding plate collides with the substrate, the kinetic energy is converted into heat energy, which melts and diffuses the thin layer interface in the bonding zone. At the same time, the collision pressure brought by high-speed impact causes the metal to undergo severe plastic deformation and the jet cleans the surface and provides good conditions for welding. Shi Changgen, Wang Yaohua et al. [2] conducted elemental scan and electron probe analysis on the obtained 1Cr18Ni9Ti/A3 sample, confirming that interface fusion and diffusion in explosive welding are not the reasons of interface bonding, and analyzed the data of explosive welding of stainless steels. Proved that explosive welding conforms to the three-stage theory of pressure welding, indicating that explosive welding is a special pressure welding.

The author believes that the melting point, plasticity and thermal conductivity of metal materials will affect the bonding of the explosive welding interface. It is not appropriate to simply assume that it is pressure welding or fusion welding or a combination of multiple welding. Under the fixed energy generated by the explosion, for the same type of material, such as welding between steel and steel, the melting point, plasticity, and thermal conductivity of the metal material have different degrees of influence on the interface bonding process; for the dissimilar materials welding, the melting of the metal on the lower melting point side may be the dominant factor, while the melting point on the higher melting point may dominate the plastic deformation. However, at present, it is only a speculation that without the support of experimental data, the explosion welding mechanism of metallic materials needs further elucidation.

### *2.2. Wave formation mechanism*

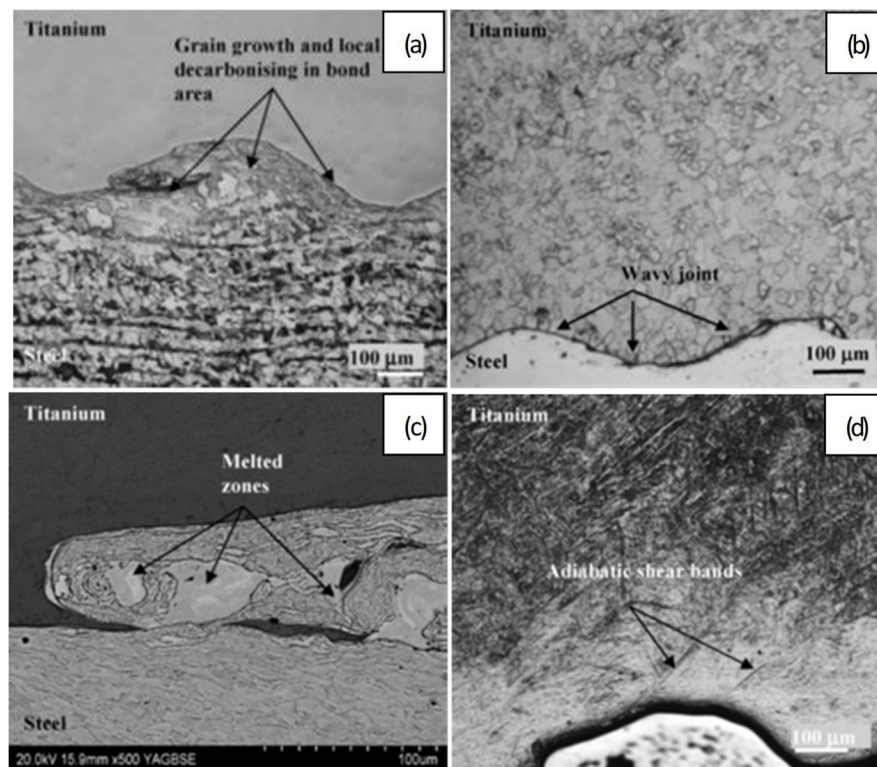
During explosive welding, the cladding plate and the substrate collide at a high speed, and a continuous quasi-sinusoidal corrugation is generated at the interface, which is called interface wave. The formation of interfacial waves is more complex and there is no recognized mechanism of wave formation. So far have been proposed jet indentation mechanism, flow instability mechanism, vortex flowing mechanism, stress wave mechanism. In recent years, Hou Guoting, Feng Jian [3] and others proposed a pulsed pool pressure welding mechanism. It is believed that the instantaneous collision point's velocity, collision angle, and the impact velocity of the cladding plate are all changed. The jet in the weld pool will weld during the welding process. During the welding process, the jet in the molten pool will make a sinusoidal motion between the base plate and the cladding plate at different angles and form a new molten pool when being hindered, thereby forming an interface wave. Compared with the mechanism of the laminar jet indentation, this mechanism considers the actual conditions of jets generated by the base plate and the clad plate, and it is close to the actual production.

## **3. Explosion welding interface research**

### *3.1. Interface Structure*

In addition to the properties of the base and the clad plate itself, the material structure and distribution of the interface have an important influence on the performance of the explosion-welded composite. In recent years, a lot of research has been carried out on the interface morphology and formation of explosive welding materials by experimental observation, theoretical analysis or numerical calculation [4-7]. Yang Liusong [4] explained the fine sublaminate structure and the formation of nanocrystals in the pearlite direction near the interface of the bridge steel/austenitic steel from the perspective of metal

melting and solidification; Han Changshun [5] systematically introduced various structures and defects on the explosive welding interface; Michal Gloc et al. [6] compared the bonding interface between the pre-annealed and annealed Ti/Fe explosion-welded composites, carefully observed the microstructures on the base and clad side near the interface, the casted microstructure in the melting zone, and the adiabatic shear. The microstructure of the cut tape, as shown in Fig.1; D. M. Fronczek [7] et al. studied the intermetallic compounds present on the Al/Ti composite interface and analyzed the microstructure of the interfaces under three different annealing regimes. Miao-Xia Xie [8] and others focused on the mechanical properties and microstructure inhomogeneity of the TA1/X65 composite plate in order to optimize the welding parameters; Guo Xunzhong et al. [9] Through the observation of the interface morphology and the performance of the welding interface, it is shown that the TA1/Al composite pipe has excellent interface bonding performance and can withstand large plastic deformation. It can be seen that scholars have achieved some results in the interface material structure of explosive welding materials in different conditions, the composition, morphology, and distribution of interface materials were clarified, and the relationship between interface material structure and mechanical properties was qualitatively studied. However, the quantitative relationship between interface material structure and material structure and mechanical properties under the service environment remains to be clarified.



**Fig.1** Microstructure of the interface in Ti-Fe by explosive welding (a) Parent plate; (b) flyer plate; (c) melted zones; (d) adiabatic shear bands.

### 3.2. Interface Mechanical Properties

Engineering components manufactured by explosive welding composite materials, which have complicated service environments and the welding interface is susceptible to shear cracking. At present, the research on the interface mechanical properties of explosive welding is mainly focused on the qualitative or semi-quantitative analysis of the hardness, tensile strength, bending strength, and shear strength of annealed composites [10]. And there is no report on the study of shear behavior and mechanism in the service environment. In the study of the interface shear behavior of explosive welding composites, many researchers used conventional methods to test the shear strength. Mustafa Acarer [11]

studied the effect of different explosive welding parameters on interface hardness and shear strength. The results show that after heat treatment, the interface waveform is stretched and the shear strength is increased. Ramazan Kaçar [12-13] tested the interfacial tensile shear of 316L stainless steel and P355GH steel obtained by explosive welding, indicating that the interfacial shear strength is between the shear strengths of the two main materials and the impact strength is significantly improved relative to the two matrix materials. Somasundaram Saravanan [14] pointed out that the nano-hardness, tensile strength, and shear strength of the composites obtained by explosive welding using 304 stainless steel as the aluminum/copper insulating layer are higher than those of aluminum/copper two-layer composites. Analyzing the above research results, scholars pay more attention to the changes in the shear strength of annealed explosive welding materials, and also explain impact factors. However, the analysis of fractures is mostly described by scanning electron microscopy (SEM). The fracture mechanics information needs to be further excavated.

#### 4. Outlook

Explosive-welded composite materials are widely used in the production of rot-resistant candle containers and equipment because of their excellent performance and low cost. They have been widely used in aerospace, petroleum, chemical, military and other fields. So far, the welding mechanism and the wave formation mechanism are not yet clear, but the process is relatively mature. The engineering components made of explosion-welded composite materials have complicated service environments and relatively weak interfacial properties. Therefore, the interface research has attracted the attention of scholars.

With the in-depth study of the interface, the use of research results to optimize the process parameters has become a consensus. Material structure analysis is a key point of interface research, including the clarification of the structure and distribution law of interface wave, transition layer, adiabatic shear band, intermetallic compounds, etc. However, the quantitative relationship between interface material structure and mechanical properties under the service environment remains to be elucidated. The prediction of the fatigue damage behavior of explosion-welded composites under service conditions will be another key to interface research. Further excavate the fracture mechanics information, combined with simulation technology, to achieve the establishment of explosive welding composite damage model under service environment and the assessment of damage behavior has certain scientific significance and engineering application value.

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