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# Research on Anti-erosion Performance and Application of Metal Foam

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***Abstract:*** *Erosion wear is an essential problem in the industrial field. When a large number of tiny particles in the fluid medium continue to impact the material, the material will often experience surface fatigue and fracture, which will cause structural damage, resulting in wear or even failure of the material surface. It is first necessary to study the mechanism of erosion wear to settle this problem. At the same time, to deal with erosion and wear, researchers try to solve the problem from the perspective of surface coating materials and erosion-resistant structures. As a new type of material, metal foam exhibits characteristics such as porosity, lightness, strength, and rigidity. In particular, the shape and structure of metal foam itself can withstand significant impact loads, and its energy-absorbing structure can effectively bear and disperse the impact of microscopic particles on the material during the erosion process. This article will start with the characteristics of the metal foam itself, discuss its anti-erosion performance, and discuss its specific application direction, expecting to put forward valuable research on the practicability and performance of the metal foam.*

***Keywords:*** *Metal foam; Erosion wear; Impact resistance; Energy absorption*

## 1. Introduction

In the industrial field, the impact of mixed fluids is often one of the normal factors affecting industrial structural components. For application scenarios such as fluid transportation pipelines, offshore drilling, and dredging engineering, it is often necessary to deal with the transmission, isolation, and shielding of sandy mixed media. These mixed media often have high quality and velocity, and high-frequency and high-complexity microscopic impacts often occur on the working surface that contacts these media [1]. When erosion and wear occur, the strength and structural stability of the material itself will inevitably be greatly affected, which in turn will affect the stable operation of the corresponding production work. The common erosion media include mud, powder, high-speed mixed gas, etc. Erosion involves many scenarios, including sand control screens, dredging pipes, engine blades, boiler pulverized coal delivery channels, etc. [1]. Through the literature search, it can be seen that when dealing with erosion and wear it is often dealt with by the characteristics of the material itself. It is often dealt with by the characteristics of the material itself, such as selecting high-performance wear-resistant metals or mixed materials, adding erosion-resistant coatings to the impact surface, etc.

This paper focuses on the research of metal foam. Metal foam, a new structural metal material, has been widely mentioned recently and incorporated into applied research. Metal foam is named for its foaming structure. While possessing many properties of metal, it has strong impact resistance and plasticity due to its microscopic pore structure. At the same time, microscopic pores can often absorb energy well when dealing with the impact of tiny particles, which in turn gives the material better erosion resistance.

The purpose of this paper is to present research regarding the anti-erosion performance of metal foam to provide a better understanding of the anti-erosion application of metal foam.

## 2. Analysis of the Erosion Wear Principle

Erosion wear refers to the impact damage to the material itself caused by a large number of tiny particles in the medium colliding with the surface of the material during high-speed and complex operation. When the impact damage reaches a certain accumulation and exceeds the metal strength and life, the material's surface will form a certain degree of surface fatigue, wear, and even fracture and peeling, which will seriously affect the component's performance [2]. Erosion and wear often occur in cement, thermal power, mining, oil drilling, and other fields. In these fields, industrial equipment is frequently exposed to challenging application scenarios such as high-speed medium transmission and shading. Erosion and wear affect the life of materials and increase production and operation costs. At the same time, it also brings hidden dangers to the safety of production and operation.

The basic principles of erosion wear will be analyzed here. In general, erosion wear differs for plastic and brittle materials and is discussed separately here.

### *2.1 Erosion Wear Principle of Plastic Materials*

In 1958, I.Finnie et al. first quantitatively expressed the relationship between erosion rate and filling angle, and based on this quantitative relationship, they proposed the theory of micro-cutting [3]. In this theory, particles impacting a metal surface are considered rigid and do not crack or deform during the impact. Under this premise, a three-dimensional activity, erosion can be further simplified as a two-dimensional problem. Assuming that the erosion volume is $V$ and the impact angle is $\alpha$, the relationship between the two can be expressed by Equation 1.

$$V = \frac{MU^2}{P} f(\alpha) \tag{1}$$

Among them, M is the particle's mass, U is the velocity of the particle when it impacts, and P is the plastic flow stress of the impact material. According to this study, $f(\alpha)$ can be expressed as a piecewise function, as shown in Equation 2. The theory proves the relationship between the impact angle and erosion through experiments. The theory especially has a good description of the enrichment of plastic materials at low-impact angles.

$$f(\alpha) = \begin{cases} sin2\alpha - 3sin^2\alpha\,, \alpha \leq 18.5° \\ \frac{cos^2\alpha}{3}\,, \alpha > 18.5° \end{cases} \tag{2}$$

Of course, in the early stage of this research, material erosion under a high-impact angle was not discussed. This study was supplemented by the follow-up study by J.G.A.BITTER et al. In the erosion scene, they proposed the theory of deformation wear. According to the theory, erosion has a relatively complex energy balance. In light of this premise, erosion wear can be divided into two categories: deformation wear and cutting wear. When the impact angle is large, the erosion wear should be mainly deformation wear, and when the impact angle is small, it should be mainly cutting wear. During deformation and wear, if the impact force of tiny particles does not exceed the yield strength of the material, the material undergoes elastic deformation within its plastic range, absorbing energy and responding to the impact. If the impact force exceeds the yield strength of the material, the material will undergo plastic deformation [4]. J.G.A.BITTER proposed expression models for the above two cases but did not verify them in physical models. In subsequent studies, J.G.A.BITTER further proposed the forging extrusion theory based on N.P.SUH's wear delamination principle. This theory measures the erosion rate of plastic materials and finds that when tiny particles impact the material at high frequency, the material's surface loses weight, which is difficult to explain with traditional theories. Therefore, J.G.A.BITTER divided the filling process into two stages: in the first stage, the impact particles produced pits and raised sheets on the metal surface but did not form abscission for the time being. In the second stage, the particles continue to impact the surface, causing plastic deformation and gradually losing surface material.

### *2.2 Erosion Wear Principle of Brittle Materials*

Brittle metals often form Hertzian cracks due to the impact of high-speed impact of rounded particles. Radial cracks will form when impacted by sharp angles. The above two kinds of cracks are related to whether the surface material forms plastic deformation. There is a significant transition period in the formation process of these two kinds of cracks, and the length and occurrence time of this transition period has a great relationship with the structure and strength of the material itself [5]. According to the research of A.G.EVANS et al., it can be seen that the size of the transverse crack is actually proportional to the size of the radial crack. Let the amount of erosion wear be $V$, and the erosion speed be $v_0$, the size of the impacting particle is $r$ and the density is $\rho$, the material fracture

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toughness is expressed as $K_C$, material hardness is $H$, then the following relationship can be obtained:

$$V \propto v_0^{3.2} r^{3.7} \rho^{1.58} K_C^{-1.3} H^{-0.26} \tag{3}$$

It can be seen that the core influencing factors of brittle metals are the characteristics of the material itself and the velocity of incident particles. As well, studies have shown that when the impact angle is small, brittle metals will also exhibit the characteristic characteristics of plastic deformation at the initial stage, resulting in surface deformation such as indentation. With the accumulation of impact, brittle metals are more likely to enter the spalling loss stage.

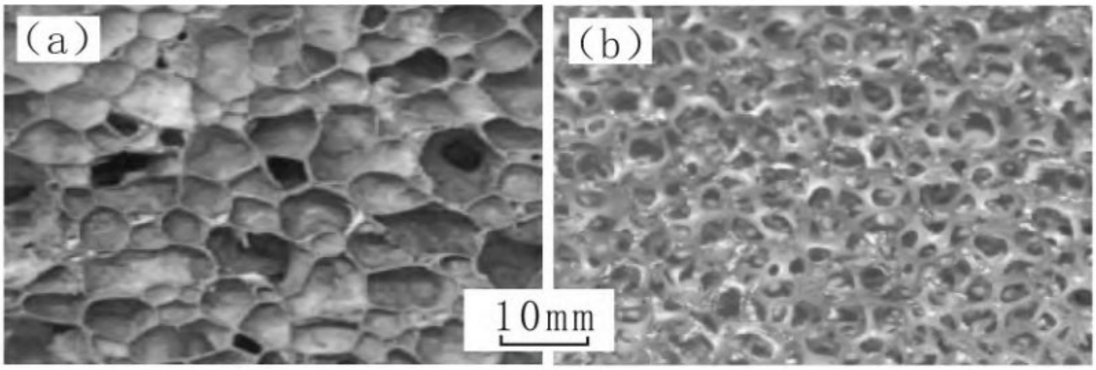
## 3. Erosion Resistance and Application of Metal Foam

### *3.1 The Concept of Metal Foam*

Metal foam is essentially a porous metal material, and its preparation is mostly prepared by foaming. A large number of pores are distributed inside the metal foam, and the distribution rate can exceed 90%, which makes metal foam have some special properties, such as its low density, light material, high strength, high energy absorption and so on. Because of its internal foam structure, the metal foam may have more metal layers in certain application scenarios, which may result in better sound or electromagnetic wave absorption.

At the same time, foam metal continues many properties of metal, such as corrosion resistance, high strength, tensile resistance and other properties. Therefore, metal foam is often used for high-strength, lightweight support structures. Due to its own structural advantages, metal foam often has good elastic deformation space and plastic deformation capacity, making it have certain advantages in impact and erosion resistance.

### *3.2 Structural Characteristics of Metal Foam*




*(a) Closed cell structure* *(b) Through-hole structure*

*Figure 1: Microstructure of Metal Foam*

As shown in Figure 1, the metal foam has two typical forms, one is the foam metal foam structure, that is, a large number of cavitation structures are formed inside the foam metal, and there are two subdivided forms of closed cells and through cells in this form. The second is a simple through-hole structure, and the connection of each internal pore-strut presents a three-dimensional network frame structure, which is a through-hole structure.

The shape of metal foam depends on its preparation method. The conventional foaming method often obtains metal foam with an irregular cavity structure. The current relatively new additive manufacturing technology can precisely control the internal structure of metal foam to form a structurally ordered metal foam [6]. A typical application is porous titanium foam metal preparation, as shown in Figure 2.

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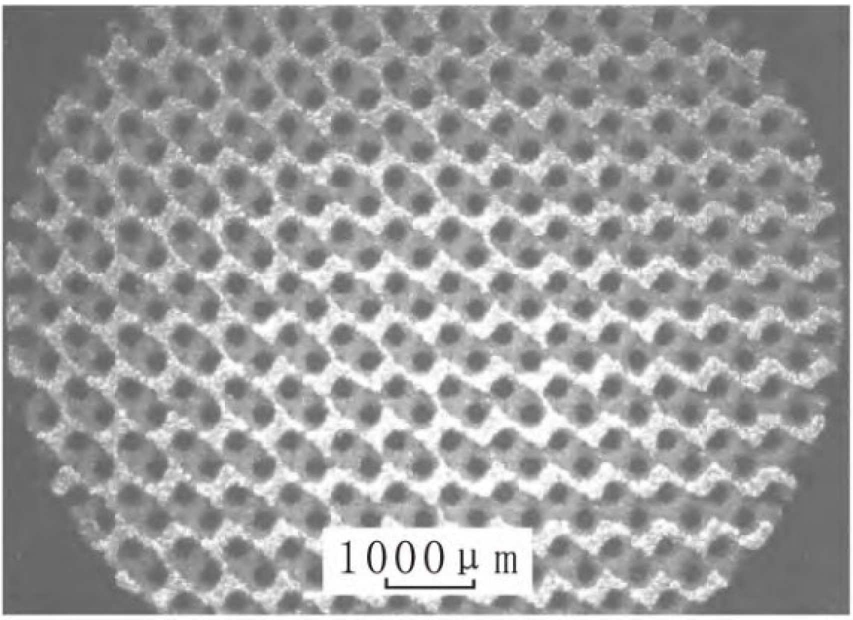


*Figure 2: Metal foam with regular porous structure*

### *3.3 Core parameters affecting the performance of metal foams*

The characteristics of metal foam are mainly low density, light material, high strength, and high energy absorption. Its erosion resistance can be extended further based on its high energy absorption and strength. The metal properties of the metal foam mentioned above are affected by some characteristics of the metal foam, and the core parameters should be porosity and energy absorption performance [7].

#### *3.3.1 Porosity*

The distribution degree of its pores can be called porosity for metal foam. This concept essentially comes from a broader range of porous materials and refers to the proportion of the actual volume of pores in the porous material to the overall volume. As mentioned earlier, there are two types of pores in metal foam: open and closed, so the porosity is also divided into open and closed. When it comes to the porosity of the material itself, it is the sum of the two porosities. For porous materials, the pore wall, as an essential supporting structure in the face of erosion, often undertakes the functions of energy absorption and deformation control, so the porosity greatly influences the performance of the metal foam.

#### *3.3.2 Energy absorption performance*

Energy absorption is the core property of metal foam and its most significant advantage. There are three stages when the metal foam is subjected to external shocks. As shown in Figure 3, when the stress it receives does not exceed its plastic deformation range, the metal foam exhibits elastic deformation, that is, $A_0$A0 in the figure. At this stage, the metal will quickly generate strain, and when the external stress continues to increase, the foam metal enters the weak deformation zone, area A in the figure, and this stage is also called the plastic zone. At this stage, the metal foam cannot maintain its shape and will undergo plastic deformation, and the shape change is often irreversible. When the stress continues to increase, the strain change no longer increases suddenly but enters a slow increase stage, which means that the shape of the metal foam becomes a dense whole, and its overall stress also rises sharply. During this process, as the stress increases, the metal foam gradually transforms from elastic deformation to plastic deformation, forming a dense, compressed body. The amount of energy it can absorb can be roughly represented by the shaded area in the figure, namely $A_0$, A, $A_s$ sum of regions[8]. It can be seen from this that the metal foam has certain energy absorption properties. The shape will not change significantly when the impact energy does not exceed its elastic deformation range.

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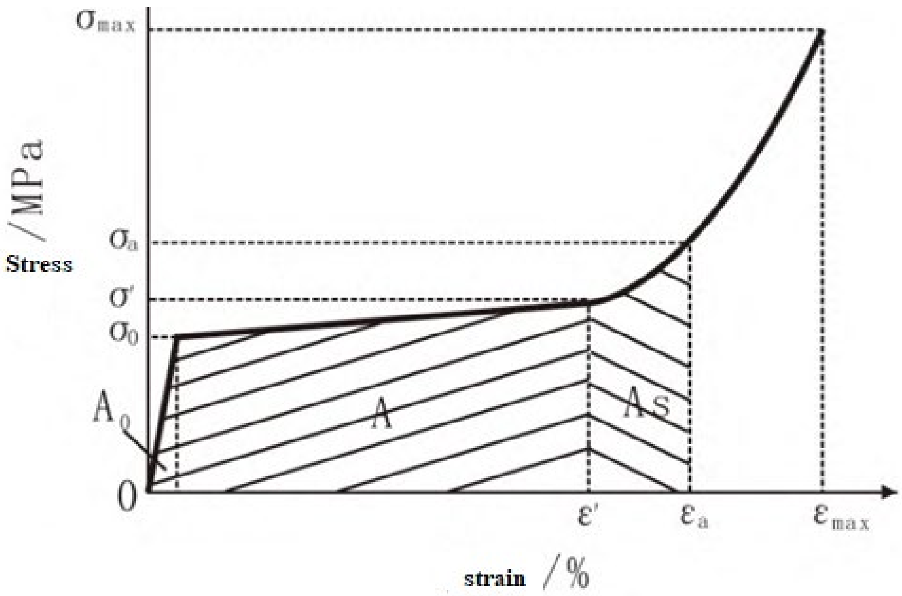


*Figure 3: Stage performance of metal foam in response to external stress*

### *3.4 Erosion resistance of metal foam and its application in sand control screens*

According to the previous analysis of the erosion principle, it can be seen that the erosion resistance of metals often depends on their energy absorption performance. The excellent energy absorption characteristics of the metal foam mentioned above can effectively deal with stress impact within a certain range and the long-term erosion of small fluid particles while maintaining its shape integrity. As mentioned earlier, it is necessary to deal with cutting and deformation wear for metal erosion. Among them, cutting wear belongs to rigidity loss. Since the shape and angle of particles are often uncontrollable during the erosion process, the only way to reduce cutting wear is to replace high-hardness materials. However, for deformation wear, the core of the wear is metal fatigue caused by metal deformation, so it can be considered to improve the energy absorption performance of materials, especially elastic deformation, to achieve energy absorption [9]. It is precisely one of the advantages of metal foam, and because of this, the metal foam has certain advantages in terms of erosion resistance. The erosion resistance of metal foam comes from its structural advantages. At the same time, its lightness makes it perform well in equipment manufacturing and application, which is of great value in offshore drilling and crude oil production. Taking the oil pipe sand control screen as an example, as the direct protective layer of oil pipe, it often has to accept repeated erosion from mud and gravel, which requires its material to have strong erosion resistance. Traditional sand control screens use high-strength metal mesh as the primary material. However, the production process of metal mesh is relatively complicated, so the application cost is high. At the same time, due to the unstable shape of the metal mesh itself, it can be regarded as a flexible material to a certain extent. Hence, its protection against pipelines is relatively poor. Based on this situation, the advantages of metal foam can be demonstrated: the light weight of metal foam can effectively control the overall weight of the pipeline protection screen; the energy-absorbing properties brought about by the metal foam's structure enable it to cope with the impact of high-frequency dense tiny particles effectively; the production process of the metal foam itself is becoming more and more mature, which further reduces its preparation and production costs.

## 4. Conclusion

Metal foam belongs to the application and exploration of new materials. So far, its preparation and production have been relatively mature. At the same time, the research on its mechanical and physical properties is also relatively mature. The foam metal itself is characterized by high energy absorption and light material, and the hardness of the foam metal can be further improved according to the material of the foam metal. It allows the metal foam to achieve better impact resistance properties. According to the erosion mechanism, this paper discusses the anti-erosion characteristics of metal foam. It takes the pipeline network protection device for offshore crude oil drilling production as its typical

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application. It is hoped that the research in this paper can provide some new ideas for the study and practice of metal foam in erosion resistance applications.

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