Functions of interlayers based on ultradisperse metal powders at diffusion bonding of heterogeneous materials

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Abstract. The features of the formation of compounds produced by means of diffusion bonding using intermediate layers based on ultradisperse nickel powder and binary mixtures made of Ni + Cu, Ni + Co, Cu + Co ultradisperse powders, have been considered. It has been demonstrated that application of such layers provides obtaining of welded joints with guaranteed quality within the temperature range of 300–350 °C and at pressures 10-20 MPa lower than those applied in the conditions of bonding without inter layers.

1. Introduction

The simplest and most convenient method of intensifying the process of diffusion bonding and ensuring the efficient operation of mechanical and thermal activation channels is the use of interlayers, which may play different functions during welding.

Interlayers are made of gold, silver, copper, nickel, aluminum and other metals in form of wire, foil, powders and films deposited on the surfaces to be bonded by electroplating or in the form of vacuum condensates. The type of interlayer is determined by the possibilities of technological production and depends on the grade of welded materials, bonding conditions, service conditions of resultant joints, etc.

A method has been developed of producing ultradisperse powders (UDPs) of metals, characterized by high activity in compacting and sintering as a result of the developed free surfaces and the presence of a large number of crystal structure defects (dislocations, vacancies, etc.) [1,2].

The effect of dispersion and the method of producing different powders on the quality of formation of the joint was examined. It showed that the diffusion bonding parameters ensuring high-quality bonds decrease with an increase in the specific surface of powder particles and an increase in the distance of their state from thermodynamic equilibrium.

2. Model description and simulation procedure

The study of diffusion bonding (temperature \( T=550 \) °C, welding pressure \( P=20 \) MPa, holding time \( t=30 \) minutes) using intermediate layers of various nickel powders such as electrolytic (PNE-1), carbonyl (PNCO-T-1) and ultradisperse, thermally decomposed nickel formate Ni (COOH) \(_2\cdot2H_2O\), with different dispersities (\( d=39.75, 7.63 \) and less than 0.1 µm) and the specific surface area \( S_u=0.12; 0.48 \) and 17.32 \( m^2/g\), respectively) showed that the maximum strength \( \sigma_u\geq20 \) kgF/mm\(^2\) is achieved when bonding through UDP.
The operation of applying UDP on welded surfaces is not technological, since it is impossible to ensure uniformity of the deposited layer in terms of thickness and mass. These features of the intermediate layer can cause instability of the structure and properties of the bonding joints, as well as lead to their poor quality. The most acceptable form of such a layer, which excludes the above mentioned drawbacks, is a porous tape obtained by rolling of the UDP of nickel. In this case, the total value of the specific surface area of the powder particles constituting the tape decreases by no more than 10%. This occurs due to the formation of interparticle contacts.

3. Simulation results and discussion

Figure 1 shows the porosity $\theta$ of the rolled strip from its thickness $\tau$ at different rolling speeds $\nu$. As the rolling speed increases, the thickness decreases and the porosity of the belt increases.

To determine the optimal values of the parameters of the rolling pattern, we investigated the effect of $\theta$, $\tau$, $\nu$ tapes on the properties of 10890 steel compounds obtained by diffusion bonding through these layers. Parameters of the bonding mode: $T=500 ^\circ C$, $P=2$ kgF/mm$^2$, $t=30$ minutes. The welded joints were tested for static stretching and the tensile strength $\sigma_u$ was determined. Analysis of the extreme dependences $\sigma_u(\tau)$ (figure 2) and $\sigma_u(\theta)$ (figure 3) shows that the maximum strength values are achieved with the following initial characteristics of the rolled strip: $\theta=50-65\%$, $\tau=60-80 \mu m$. With increasing $\nu$, the values of $\sigma_u$ decrease.

Figure 1. Dependences of $\theta(\tau)$ for various $\nu$: 1 - 190; 2 - 470; 3 - 790; and 4 - 1570 mm/min

Figure 2. Dependences of $\sigma_u(\tau)$ for various $\nu$: 1 - 190; 2 - 470; 3 - 790 and 4 - 1570 mm/min

Figure 3. Dependences of $\sigma_u(\theta)$ for various $\nu$: 1 - 190; 2 - 470; 3 - 790 and 4 - 1570 mm/min

Figure 4 shows the dependencies $\sigma_u(t)$, reflecting the change in the relative tensile strength of the bonded joints of steel 10890 + steel 10890. These results show that with diffusion bonding parameters $T=500-600 ^\circ C$, $P=1.5-2.0$ kgF/mm$^2$ and $t=20-30$ min $\sigma_u$ approaches 0.8. When bonding without a
powder intermediate layer, this strength can be obtained at $T=900 \, ^\circ\text{C}$, $P=2-2.5 \, \text{kgF/mm}^2$ and $t\geq30 \, \text{min}$. Such an increase in temperature and such bonding pressure is especially relevant when connecting special materials, for example, permanent magnets with magnetic circuits and fittings, in which the loss of the initial magnetic properties occurs at temperatures above 550 $^\circ\text{C}$.

![Figure 4](image)

**Figure 4.** Dependences of $\bar{\sigma}_u(t)$ at $T=400$ (a), 500 (b) and 600 $^\circ\text{C}$ (c), $P=0.5$ (1), 1 (2), 1.5 (3) and 2 kgF/mm$^2$ (4)

The sintering of a powder layer consisting of one component is accompanied by a decrease in free energy due to a decrease in the total surface area of the interparticle pores. An intermediate layer containing several components, together with excess free energy due to the presence of defects in the structure and the developed surface of its constituent dispersed particles, also has excess energy associated with the possibility of forming an alloy. Another important feature of the powder intermediate layers is that, by varying their composition, it is possible to ensure its compliance with the chemical composition of the welded materials. Consequently, it is possible to obtain welded joints, which have not only high strength characteristics, but also the same electrophysical properties as the main materials.

The investigations were carried out using UDP mixtures obtained from mechanical mixtures of nickel + copper, nickel + cobalt and copper + cobalt formats with a different ratio of components.

The strength of the joints produced through the interlayer of mechanical mixtures of nickel + copper UDP at 400 $^\circ\text{C}$ varies in the range of 20-50 MPa, depending on the ratio of the components (figure 5 a). In mechanical tests of these specimens, the contact surface contains individual areas of bonding. With increasing temperature, the strength naturally increases, and the dependence becomes “wavy” with the maximum strength corresponding to the composition 25%Ni+75% Cu and the minimum strength to 75%Ni+25% Cu.

The strength of the joints bonded through an interlayer of mechanical mixtures of nickel + cobalt increases with increasing the nickel content in the mixture (figure 5 b). With an increase in the cobalt content in mechanical mixtures of the cobalt + copper UDP, the strength of the welded joints rapidly decreases (figure 5 c).

4. Conclusion

Optimum results in welding dissimilar materials (formation of full-strength joints, reduction of temperature and pressure of the process, formation of special properties, etc.) can be obtained using UDPs and mixtures of UDPs produced from formats or mechanical mixtures of formats.
Figure 5. Strength of bonding joints produced through interlayers of UDPs of mechanical mixtures: Ni + Cu (a); Ni + Co (b); Co + Cu (c); 1-5 – $T=400, 500, 600, 700$ and $800^\circ$C, $P=2$ kgF/mm$^2$, $t=30$ min

References
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