Article ID: 1003－6326(2003)02－0276－04

Interfacial bonding state on different metals Ag, Ni in cold pressure welding①

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Abstract: The interfacial bonding state for the different metals Ag, Ni without metallurgic are actions was studied. The tensile test of the joint concludes that the bonding strength of Ag, Ni in cold pressure welding is strong enough to satisfy the demand of application, while the value of bonding strength is larger than that of Ag base. The conclusions further signify that the metals(hardly being mutual soluble) can be welded, and supply extremely important references to the further study either on test or theory for the weldability of different metals. The theoretical analysis and calculations of the bonding strength were made on the base of thermodynamics, crystallography, solid physics etc. Moreover, by means of microscopic test and analysis, especially drawing support from the research of Al-Pb, this strong bonding mainly depends on the mechanical bonding power and metal atomic linkage, but not on the atomic diffusion.

Key words: metallurgic reactions; cold pressure welding; interface bonding
CLC number: TG 453.4 **Document code:** A

1 INTRODUCTION

The technology of cold pressure welding is widely used to achieve the joining of the same or different metals with different thermophysical properties and other conditions, for it spares energy sources, simplifies welding equipments, does not need to be heated, and does not cause the melting, the heat effect zone and the brittle compounds. Accordingly the technology may be satisfied with the demand of comprehensive properties in industry application, and will solve the conflict between the increasing deficiencies and growing demands. On the side of metallurgic ability[1], the studies on different metals that are unlimitedly soluble (Ni-Cu) or limitedly soluble (Ag-Cu) and can form compounds (Al-Cu), have attained achievements, but on the metals without being soluble(Ag-Ni, Al-Pb) are still an impending problem.

As we know the welding of different metals is more difficult than that of the same metals. The fact is influenced by the following factors: metals, physical properties, chemical properties; and to a great extent, the difference of two kinds of metals, especially, the difference of crystal lattice type, crystal lattice parameter, atomic radius and so on. Ref [2] named it "metallurgic insolubility". For the match of Ag-Ni, the pressure welding and other complex welding technology have firstly to be used. Allowing for the special technology of cold pressure welding illustrated by the above, this paper adopt this technology for Ag, Ni welding.

2 TENSILE TESTING

The materials were Ag , Ni all with purity of 99.99%, namely, fine silver, pure nickel; all those materials were annealed relating with machining.

Three groups of Ag-Ni samples with diameter of 1.0 mm were cold pressure welded and extruded for four times.

The equipment of tensile test was electron-pull tension testing machine with model number of DI-1000B. The purpose of tensile testing is to determine the bonding strength of different metals.

All tensile test results are listed in Table 1, the rupture was located at the base Ag and the average breaking strength is 176.9 MPa. As we can see, even they do hardly have mutual solubility, but can form strong joint by the means of cold

Table 1 Data of tensile test for joint Ag-Ni

Sample	Value read by machine at moment of fracture		Value calculated at moment of fracture	
	displacement/mm	loads/N	strain/%	stress/MPa
1	22	560	0.009 2	178.3
2	16	554	0.006 7	176.3
3	20	556	0.009 2	176.3
Average value	19.6	556	0.007 8	176.9

① **Received date:** 2002－04－01; **Accepted date:** 2002－06－03
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pressure welding and even abide by the general rule that the bonding strength of interface is higher than that of the relative soft base metals.

3 ANALYSIS OF BONDING STRENGTH

In this paper, the interface[3, 4] refers to the bonding zone of two metals welded, and it is only several nanometers thick(generally several atomic layers). The interface with peculiarity not only influence the whole joint properties, but also decide the strength, the conduction of electricity, the thermal conduction etc of the joint. It has taken effect on the application of different metals bonding in industry. First of all, the interfacial stability is directly decided by the value of its energy.

The bonding energy of interface, or the bonding strength of interface of solids, is the reflection of the bonding energy of interface. The bonding energy[5, 6] generally is defined as, under 273 ℃, the energy difference between the balance energy of free state, for the former, it refers to the whole interactive energy of atom, namely, the force is the result of the strong bonding energy that exist between the atoms on the interface.

In terms of classical theory about the interaction of atoms the transformation of the atomic interactive forces follow with the change of distance between two free atoms (Fig. 1).

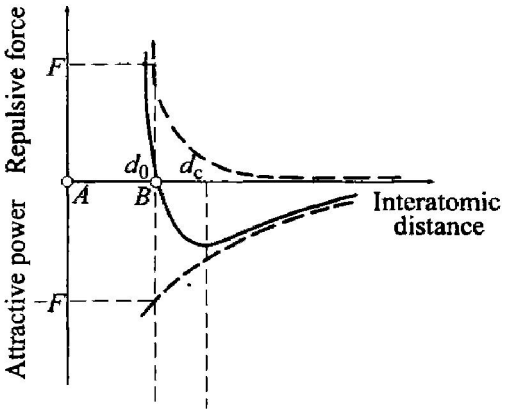

Fig. 1 Relation of atomic distance and interactive forces

Let the atomic distance in the state of balance be r_0, which is assumed to be reduced by pressure. Obviously it needs to overcome the rapidly increasing repulsion; on the contrary, r_0 is assumed to be increased by dragging forces, the general curve firstly have the highest value, then drop with the increasing of atomic distance. Actually, at the point of the largest value, the distance will attain infinite. To some extent, this paper popularizes the above theory, and applies it for two rows atoms. In this condition, there exist critical stress that cause appearance of new interactive forces that can be reflected by the potential functions. Among many potential functions, Leonard-Jones potential[7] is more suitable to metal crystal. The model is as

$$\varphi = 4\varepsilon[(\eta/r_{ij})^{12} - (\eta/r_{ij})^{6}] \quad (1)$$

where ε, η are potential parameters.

For the number of atoms is N, potential energy is

$$E = \frac{1}{2}N\sum_i \varphi = 2\varepsilon N\sum_i [(\eta/r_{ij})^{12} - (\eta/r_{ij})^{6}] \quad (2)$$

$$\left.\frac{\partial E}{\partial r}\right|_{r=r_0} = 0 \quad (3)$$

$$\left.\frac{\partial^2 E}{\partial r^2}\right|_{r=r_0} = \beta r_0/K \quad (4)$$

$$E|_{r=r_0} = E_{ab} \quad (5)$$

where β is parameter related to the crystal lattice; K is compressing parameter; E_{ab} is bonding strength.

For FCC[8], the following can be deduced from Eqns. (3), (4), (5)

$$r_0 = 1.09\eta \quad (6)$$

$$\eta = (75\varepsilon/K)^{1/3} \quad (7)$$

$$\varepsilon = -E_{ab}/(8.6N) \quad (8)$$

The above is only in agreement with the metals of FCC themselves, but for the interface, the potential parameter can be decided by normal bonding regulation that is, for the distance, taken the arithmetic average; for energetic parameter, taken the geometric average[9], the result of calculation is

$$\eta = (\eta_1 + \eta_2)/2 \quad (9)$$

$$\varepsilon = \sqrt{\varepsilon_1 \varepsilon_2} \quad (10)$$

For Al-Pb, Ag-Ni system, the simulated potentional parameters[10] of Leonard-Jones are listed in Table 2.

Table 2 Parameters for pure metals(Ag, Ni)

Materials	ε/eV	η/eV
Ag-Ag	0.344 2	0.263 83
Ni-Ni	0.515 7	0.227 34

From Eqns. (9), (10) and Table 3, it can be deduced:

$$\varepsilon_{Ag\text{-}Ni} = 0.421\ 3 \qquad \eta_{Ag\text{-}Ni} = 0.245\ 59$$

From Eqns. (6), (7), (8) and the value of ε, η:

It can be concluded for the value of bonding strength:

$$E_{ab,\ Ag\text{-}Ag} < E_{ab,\ Ag\text{-}Ni} < E_{ab,\ Ni\text{-}Ni}$$

Table 3 Value of E_{ab}, r_0

Materials	E_{ab}/eV	r_0/nm
Ag-Ag	2.96	0.282 32
Ag-Ni	3.62	0.262 78
Ni-Ni	4.44	0.243 25

The theoretical calculation explained the result of test that the fracture appearing on the base Ag, but not on the joint of Ag-Ni, and the former and the later are unanimous.

4 TEST AND ANALYSIS OF INTERFACIAL BONDING MECHANISM

There are many references about the bonding mechanism of cold pressure welding at home and abroad. At home, the main opinions hold that the theory of being no diffusion; abroad, many suppositions are made, for example: 1) the theory of thin membrane: materials' weldability is depended on the state to be welded, not on the properties of materials themselves ; 2) the theory of re-crystal: it thinks that the process of cold pressure welding is the course of re-crystallization, from the aspect of nature; 3) the theory of dislocation: in cold pressure welding, the plastic deformation of metals caused by the pressure can cause the appearance of dislocations, and the dislocations move to the surface of metals, destroying the oxidizing membrane and leading to the achievement of bonding; 4) the theory of diffusion: it hold the opinion that the bonding mechanism is mainly atomic diffusion; 5) the theory of energy: the requirement of metals bonding is atomic energy but not diffusion. The above concluded from various forms of pressure welding, to some extent, are reasonable, but they can not explain all kinds of bonding mechanism of Ag-Ni, Al-Pb in cold pressure welding. Apparently it is necessary to further study in this field.

In order to analyze the interfacial state, this paper adopt X-ray diffraction and other microscopic test (see Fig. 3). From Fig. 2 no compounds and solid solution appear on the interface[11, 12].

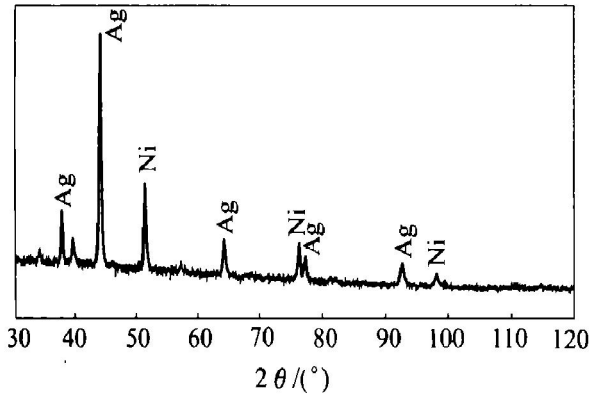

Fig. 2 XRD pattern of interface of Ag-Ni

Now that the case is the above, then the theories[13, 14] about the joint mechanism of Al-Cu (forming compounds), Cu-Ni (unlimited soluble), Ag-Cu (limited soluble) can not be fitted for that of Ag-Ni. From the microscopic test of Ag-Ni, we can conclude the following results that super-saturated solid solution either exist during the course of welding or not appear on the interface. For the latter, it is easy to deduce that the mechanism of the joint Ag-Ni is mechanical bonding force and metal atomic linkage but not atomic diffusion; for the former, now that the point presume the form of super-saturated solid solution during the cold pressure welding, we can adopt the methods of mechanical alloying to discuss. Moreover the research of Al-Pb is helpful to understand deeply the mechanism of the bonding Ag-Ni, for Al-Pb belongs to the kind of Ag-Ni from the side of metallurgic reaction. Some documents adopt the methods of mechanical alloying to study the Al-Pb. From Fig. 4 and Fig. 5, the super-saturated solid solutions appear on the picture, and the reason is that the change of lattice constant for phase Pb is more obvious than that of the phase Al[15, 16].

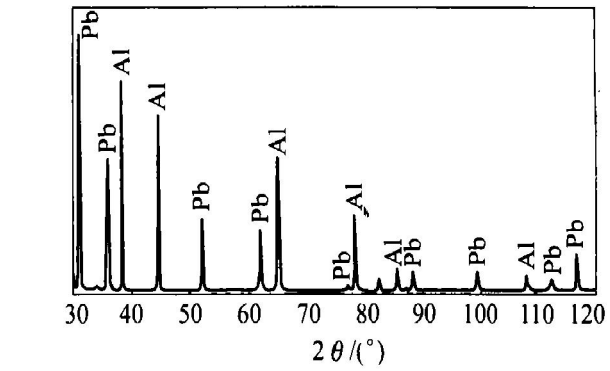

Fig. 3 XRD pattern of interface of Al-Pb

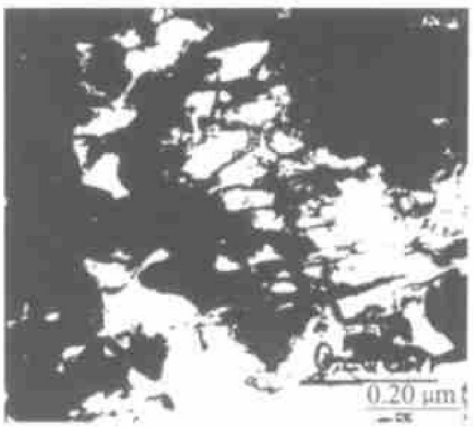

Fig. 4 TEM image of Pb-50%Al (15 h)

It is clear that the solution is unstable, then deposit, forming the little particles. Regarding to the Ag-Ni, during the process of cold pressure welding, many plastic deformation cause crystal defects and stress concentration on the interface. All these factors can increase the diffusion coefficient and may cause the forming of solid solution that deposit accompanied with the fracture of the joint because of being extremely unstable. Allowing for the above analysis, for the joint of Al-Pb in cold pressure welding, the X-ray diffraction are carried out (Fig. 3). Similar to the test

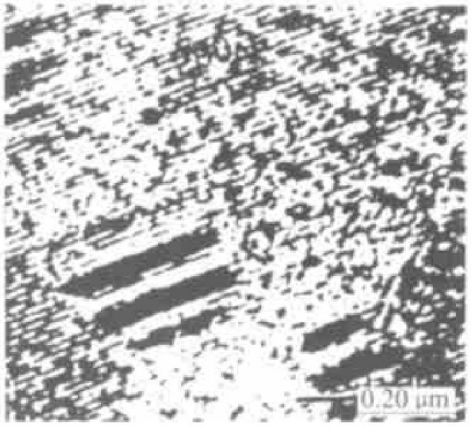

Fig. 5 HREM image of Pb-50%Al(15 h)

of Ag-Ni, from Fig. 3 no compounds and solid solution appear on the interface of Al-Pb. So we can deduce the super-saturated solid solution may be occurred during the cold pressure welding, but it is unstable. Companying with the separating out of super-saturated solid solution, the joint should break apart. If the mechanism of Ag-Ni and Al-Pb is atomic diffusion, the separating out would lead to the fracture of the joint, factually, the joint is very sound. In view of the above analysis, no phenomena of fracture about the joint Al-Pb and Ag-Ni. It can be concluded that strong bonding of the joint Ag-Ni is caused by mechanical bonding force and metal atomic linkage, not by atomic diffusion. In order to achieve good joint, it is indispensable to clean the contact face and further propel more activation core, finally forming the stable bonding.

5 CONCLUSIONS

1) The tensile test of the joint Ag-Ni suggested that the bonding strength of Ag-Ni in cold pressure welding is strong enough to satisfy the demanding of being used , namely, even for the match of Ag-Ni without metallurgic reaction has good weldability under the condition of cold pressure welding.

2) This paper adopt the thermodynamics, crystallography, solid state physics to build the mathematic model of bonding strength, especially made calculation on the base of Leonard-Jones potential functions, proving the bonding strength to be stronger than that of the Ag base.

3) By means of microscopic test and analysis, it proved that the mechanism of interfacial bonding for this kind of Ag-Ni, Al-Pb mainly depends on the mechanical bonding force and metal atomic linkage, not on the atomic diffusion.

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(Edited by LONG Huai-zhong)