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Explosive compaction of CuCr alloys①

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[Abstract] The production of CuCr alloys utilizing explosive compaction was studied. Mixture powders of CuCr alloys placed in tubes with a dimension of *d*14.0 mm × 21.4 mm can be compacted using explosive pads of 16.5 mm or 22.5 mm. Thicker pads of explosive make the compacts more porous. The effects of the ratio of m_e/m_p, ratio of $m_e/(m_p+m_t)$ and impact energy on the density of compacts were similar, they were chosen to control explosive compaction, respectively. When adequate value of the parameters m_e/m_p, $m_e/(m_t+m_p)$ and impact energy of unit area of tube was chosen, high density(7.858 g/cm^3), high hardness(HB189) and low conductance (13.6 MS/m) of CuCr alloys could be made by explosive compaction. The general properties of CuCr alloys by explosive compaction are similar to those of CuCr alloys by traditional process.

[Key words] explosive compaction; CuCr alloys; properties
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1 INTRODUCTION

Now CuCr contact materials with superior integrated characteristics have been used in mid-voltage vacuum breaker broadly[1]. With development of vacuum switch to high voltage, large capacity and little size, CuCr contact materials should be further improved for some properties, so as to be satisfied with real use of vacuum switch. Many studies showed that CuCr contact materials with fine microstructure, uniform compound, or fine Cr particle can behave excellant properties[2, 3]. So it is essential and useful that CuCr contact materials with finer grain be obtained.

The most commonly used P/M method for producing CuCr alloys comprises the following processing steps: mixing, cold compacting, sintering or hot pressing[4, 5]. This conventional route has two disadvantages: firstly, it is expensive due to high capital investment and long processing time; secondly, prolonged high temperature exposure during the sintering or hot pressing destroys the mechanically alloyed fine-scaled microstructure in the CuCr powder and gives rise to separation of Cu and Cr. This leads to the formation of coarse grain and compound separation. In the present investigation, the compaction of Cu and Cr powder mixture is examined utilizing the explosive compaction route. In explosive compaction, pressures up to 2.6 GPa (which only last for several microseconds) can be generated by the energy released from the explosive charge[6]. Explosive compaction of powders involves particle deformation at very high speeds. Deformed particles are mechanically locked and welded together, producing compacts of high density. It has been suggested that the interparticle bonding in dynamically compacted materials is a result of localized energy deposition and melting at the particle interfaces which occur as the particle undergo shear and deformation during densification[7~9]. Intense localized plastic deformation near particle boundaries and interparticle friction convert most of the shock energy into heat[10]. This route has the potential to be an economical method of producing composites from powder mixture. It also minimizes deleterious effects on both the compound separation and grain growth.

In the explosive compaction of powders, investigators have listed a variety of factors controlling the compaction process. Prümmer[11] explained the densification of powder on the basis of the detonation velocity(v_d) of the explosive, he also correlated the final densities with the square of the detonation velocity of the explosive used. Since the square of the detonation velocity is directly proportional to detonation pressure, the compaction behaviour of the powders will be governed by the detonation pressure. In other work, it was observed that a more-detailed understanding of the compaction process could be attained by taking into account the consolidation parameter $m_e/(m_t+m_p)$ in which the role of the metal container was considered in the densification step[12], where m_e= mass of explosive, m_p= mass of powder, and m_t= mass of tube. The impact energy was used to compact powder by a number of workers[13, 14]. In the present investigation, an attempt has been made to delineate the controlling parameters which are predominant in the compaction of CuCr powder mixture.

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2 EXPERIMENTAL

2.1 CuCr powder mixture by mechanically alloying

Cu element powder and Cr element powder (their mass ratio is 1:1) and grinding balls were put in grinding barrel together and ground. The mass ratio of ball to powder was 10:1, the grinding velocity was 400r/min and grinding time was 10 h. The microstructure of mechanically alloyed powders were studied by XRD and SEM.

2.2 Explosive compaction

A common arrangement[15] for explosive compaction is shown in Fig. 1. The powder is encapsulated in a metal tube and surrounded by a uniform layer of explosive. Detonation of the explosive charge from one end of the assembly produces a convergent cylindrical shock wave which collapses the tube and compacts the powder. In experiments a similar arrangement was used and the compaction of the powder was carried out in 40# seamless steel tubes. One end of the tube was closed by a plug and the powder was vibratory packed to uniform density along the length of the tube. Subsequently, the tube was closed by means of a second plug and the tube assembly centrally located inside a cylindrical cardboard. A wooden cone was placed at the top of the tube in order to modify the compression front that results from detonating the explosive charge. The annular cavity between the metallic tube and the cardboard was packed to a uniform density with explosive powder carbamide nitrate. This sheath is called the explosive pad. Detonation of the explosive charge was carried out in the vertical position, and the electric detonator caused blasting.

Two sizes of steel tubes, d21.4 mm × 150.0 mm × 1.3 mm and d14 mm × 100 mm × 2 mm were used. The shorter tubes and the longer tubes were used in combination with four thicknesses of explosive pads.

2.3 Post-sintering treatment

After compacting, the container tubes were removed and the compacts were sintered at 900 ℃, under 10^{-2} Pa for 8 h in vacuum sintering furnace. Their density, rigidity and conductance were tested after they were sintered, and were compared with CuCr alloys by commonly used P/M approach.

3 RESULTS AND DISCUSSION

Ref. [16] showed that the component of Cu and Cr is uniform and the average size of grains is about 50 nm.

Results of the experiments are listed in Table 1. For the shorter steel tube, the densities of the compacts were observed to remain essentially the same when the explosive pad thickness varied from 15.0~16.5 mm. When the explosive pad thickness increased above 17.5 mm, we observed a fall in the density of the compacts and central piping was also observed when the pad thickness was 25 mm. Similar results were found in the case of the longer steel tube. From the information obtained from the two sets of experiments, compaction of the powder was performed in shorter tube with 16.5 mm pad thickness, in longer tube with 22.5 mm pad thickness. This resulted in the relative density of 98.63%.

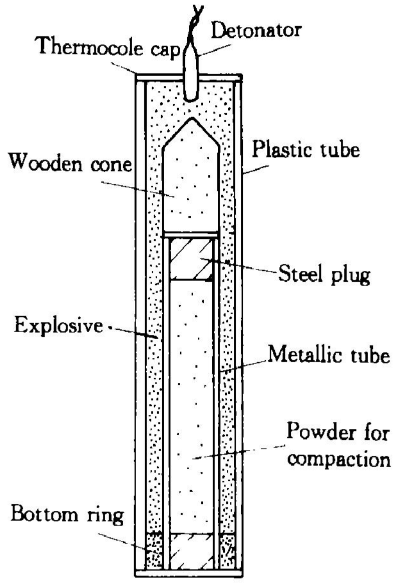

Fig. 1 Experimental set up for explosive compaction

Table 1 Role of explosive thickness on density of CuCr compacts

Sample No.	Tube sort	d_t/mm	Tube wall thickness /mm	Explosive layer thickness /mm	m_e/m_p	$m_e/(m_p+m_t)$	ρ_r/%
31				15.0	2.923	1.163	97.22
32				16.5	3.362	1.338	98.69
33	Shorter	14.0	2	17.5	3.776	1.503	98.63
34				20.0	4.005	1.594	96.76
35				25.0	4.575	1.783	92.14
41				15.0	1.270	0.839	93.28
42				18.0	1.427	0.943	95.34
43	Longer	21.4	1.3	20.0	1.713	1.132	98.02
44				22.5	1.998	1.321	98.65
45				25.0	2.330	1.540	97.52

The effect of the mass ratio of explosive to powder (m_e/m_p) on density of the compacts is shown in Fig. 2. The density increases with increasing the ratio m_e/m_p up to a certain level but then it decreases. The effect of the mass ratio of the explosive to the combined collapsible tube and the powder $m_e/(m_p+m_t)$ on density of the compacts is shown in Fig. 3. The highest

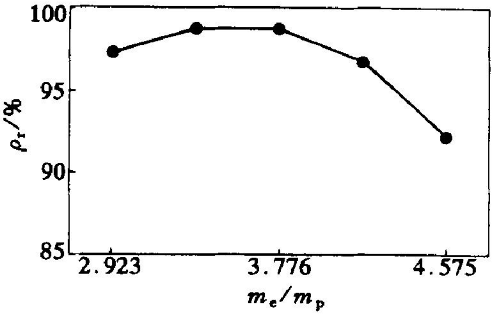

Fig. 2 Effects of m_e/m_p on compacts density

densities were achieved when the above ratio was maintained between 1.163~ 1.594. Further increase in the ratio results in porous, softer compacts.

The effect of impact energy on the density of the compacts was also investigated. The impact energy of unit area of the collapsible tube was calculated using the equation[17]:

Impact Energy= $0.5\ \rho t v^2$ (1)

where ρ= density of the tube material, t= thickness of the tube and v = velocity of the tube. The tube velocity was calculated by the equation given by Chadwick[18]:

$v = v_d[0.612R/(2+R)]$ (2)

where v_d= detonation velocity of the explosive; R = mass ratio of the explosive to powder.

In our work, the detonation velocity of the explosive was supposed 3 100 m/s, the tube velocity and the impact energy of unit area of the collapsible tube were calculated, as listed in Table 2. The effect of impact energy on the density of the compacts was shown in Fig. 4.

From Table 2, It is known that the impact energy of unit area in the shorter tubes was varied from 989 to 1 360 J/cm^2, and in the longer tubes varied from 275 to 530 J/cm^2. Compared with shorter tubes, wall thickness of the longer tubes was thinner, the mass ratio of m_e/m_p was smaller, then the impact energy of unit area in the longer tube was rather smaller than that in the shorter tube. In Fig. 4, It is known that the density increases with increasing in the impact energy to a certain level but then it decreases, appearing a maximum. The effect of the impact energy on density of compacts was similar to that

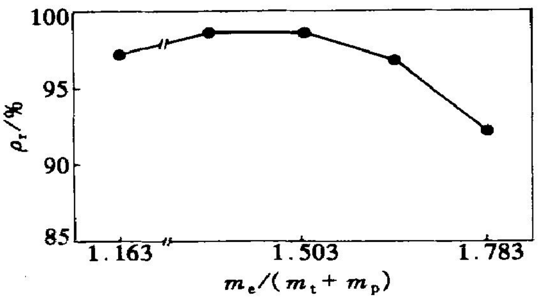

Fig. 3 Effects of $m_e/(m_t+m_p)$ on compacts density

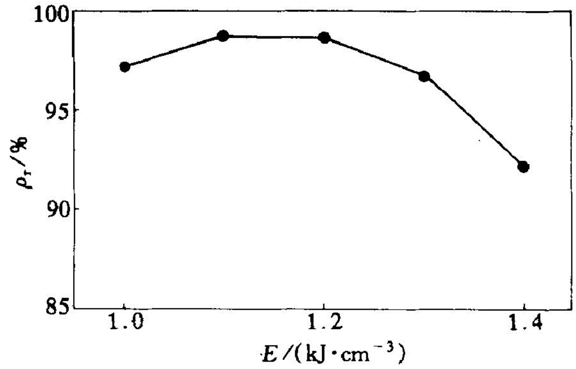

Fig. 4 The effects of impact energy on compacts density

of the mass ratio of m_e/m_p or $m_e/(m_p+m_t)$.

The density, rigidity and conductance of the compacts were tested after they were vacuum heat-treated, and were compared with that of CuCr alloys by traditional sintering, as seen in Table 3. Generally spearking, their properties were similar, the density and the rigidity were larger, the conductance was much lower than those of the compacts after vacuum sintered. This reason may be that the vacuum sinter-treatment was not enough, if treatment temperature further higher, treatment time was further longer or vacuum degree further higher, maybe hardness should be lowed and conductance be enhanced. In the end the general properties will be similar.

On the basis of the following equation[17]:

$P = 0.25\ \rho_e v_d^2$ (3)

Table 2 Impact energy of unit area of collapsible tube

Sample No.	m_e/m_p	Tube velocity /(m•s^{-1})	Tube wall thickness /mm	Impact energy per unit area/ (J•cm^{-2})
31	2.923	1 126.5		989.734
32	3.362	1 189.6		1 103.726
33	3.776	1 240.3	2.0	1 199.908
34	4.005	1 265.3		1 248.768
35*	4.575	1 320.1		1 359.278
41	1.270	736.8		275.262
42	1.427	790.0		316.419
43	1.713	875.3	1.3	388.438
44	1.998	948.1		455.739
45	2.330	1 020.9		528.414

* Detonation velocity/(m•s^{-1}) is 3 100 m/s, tube density is 7.80 g/cm^3.

Table 3 Comparison of properties of CuCr alloys by different processes

Preparation process	Density/ (g•cm^{-3})	Hardness HB	Conductance /(MS•m^{-1})
Explosive compaction+ sintering-treatment	7.858	189	13.6
Melt-oozing[4]	7.840	123	19.1
Hot pressing[4]	7.820	134	17.6

In our work, the explosive density $\rho_e = 0.975$ g/cm^3, and the detonation velocity of carbamide nitrate $v_d = 3\ 100$ m/s, then detonation pressure was 2.342 GPa. The adequate parameters were chosen listed in Table 4.

In all experiments, the curves of the effects of three process parameters were similar. So choosing one of them m_e/m_p, $m_e/(m_p + m_t)$ and impact energy, we can dominate the process of explosive compacted CuCr alloys.

The properties of the compacts after pro-sintered treatment were compared with those of melt-oozing or hot pressing, the procedure of explosive compaction is simpler, while the conductance is lower than that of traditional process. If adequate vacuum sintered treatment were adopted, the properties of CuCr alloys would be similar to those by other processes.

Table 4 Adequate process parameters

Tube	m_e/m_p	$m_e/(m_p+m_t)$	Explosive pad thickness /mm	Tube velocity /(m·s^{-1})	Impact energy per unit area of tube/ (J·cm^{-2})
Shorter	2.726	1.105	16.5	1094.3	934.044
Longer	1.998	1.321	22.5	948.1	455.739

4 CONCLUSIONS

1) Mixture powders of CuCr alloys placed in tubes with an internal d14.0 mm or 21.4 mm can be compacted using explosive pads of 16.5 mm or 22.5 mm. Thicker pads of explosive make the compacts more porous.

2) The effects of the mass ratio of m_e/m_p, the ratio of $m_e/(m_p + m_t)$ and impact energy on the density of compacts are similar, one of them is chose to control explosive compaction.

3) When adequate value of the parameters m_e/m_p, $m_e/(m_p + m_t)$ and impact energy of unit area of tube are chosen, high density, high rigidity and low conductance of CuCr alloys can be made by explosive compaction.

4) These general properties of CuCr alloys by explosive compaction are similar to those of CuCr alloys by traditional process.

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