ENERGY RELATIONS IN THE COMPACTION OF BINARY POWDER MIXTURES

N. F. Kunin*, B. D. Yurchenko,
and N. V. Myshkina

Study of energy relations in compaction is based on measuring the work of compaction, the heat being evolved, and the energy being absorbed by the material [1]. The last of these quantities may be obtained as the difference between the work of deformation and the heat evolved.

In the compaction of powder mixtures, mutual diffusion of the components undergoing deformation takes place in the contact regions. As a result, surface solid solutions are formed. The diffusion leads to a nonmechanical densification of the material, which lowers the work of deformation and increases the amount of heat evolved in the form of heat of diffusion. For this reason, the energy absorbed in the compaction of mixtures is lower than that absorbed in the compaction of pure metals.

In the first approximation, it may be assumed that the decrease in the energy absorbed is equal to the heat of diffusion. With this assumption, it is possible to perform certain calculations, the results of which are presented below. It may be noted that, owing to the diffusion phenomena in surface layers, energy absorption is not an additive function of concentration.

EXPERIMENTAL METHOD AND RESULTS

Powder mixtures were pressed, as in the earlier studies [1, 2], using a UM-5 tensile testing machine, in a die of 14-mm diameter at a punch-travel rate of 4 mm/min. The final compact height was approximately equal to the compact diameter. The test temperature was 20°C.

During compaction, two diagrams were recorded simultaneously. One of these, pressure vs punch travel, was recorded by means of the diagram-plotting apparatus of the testing machine and the other, temperature vs compaction time, with an electronic potentiometer. The characteristics of these diagrams could readily be compared for any instant of compaction, because the rate of compaction was constant. By processing compaction indicator diagrams, values of density at various specific pressures were obtained, and in addition specific work of compaction was computed. The work of elastic deformation of each powder and of the press components was subtracted from the total work.

Using a differential thermocouple, the compact and die temperatures were measured at various points. Once the temperatures to which different zones in the die were heated up were determined, it was possible to calculate the amount of heat evolved. The heat lost to the surrounding atmosphere during compaction was calculated from a cooling curve recorded after the cessation of compaction.

Thus, using experimental data on work of compaction, energy of elastic deformation, temperature rise in the material, and heat received by the die as a result of the cooling of the compact, and knowing the mass of the material and its specific heat, it was possible to determine the energy absorbed by the material being densified.

To prepare mixtures, use was made of industrially-manufactured aluminum, iron, and copper powders, as well as a zinc powder obtained by the mechanical comminution of solid metal. The specific surface area, measured with a Tovarov instrument, was 800 cm^2/g for the aluminum powder, 590 cm^2/g for the iron powder, 1374 cm^2/g for the copper powder, and 727 cm^2/g for the zinc powder.

---

*Deceased.

Moscow Institute of Chemical Engineering. Translated from Poroshkovaya Metallurgiya, No. 9(69), pp. 25-30, September, 1968. Original article submitted August 4, 1966.

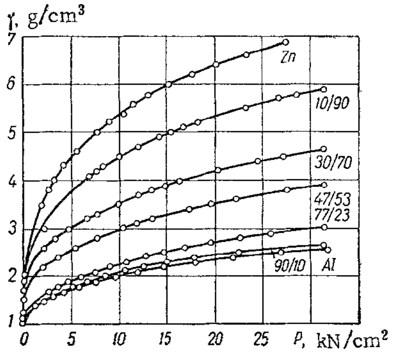


Fig. 1

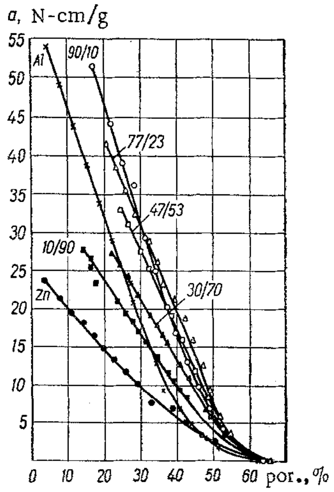
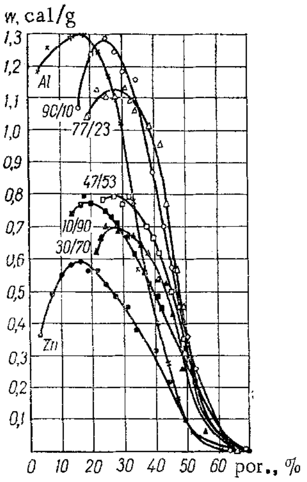


Fig. 2

Fig. 1. Compaction curves for Al + Zn mixtures.

Fig. 2. Influence of porosity on specific work of compaction for Al + Zn mixtures.



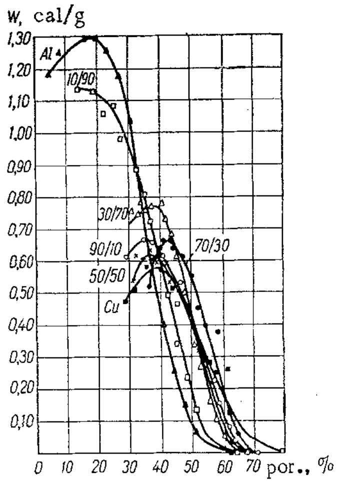


Fig. 3

Fig. 4

Fig. 3. Influence of porosity on energy absorbed for Al + Zn mixtures.

Fig. 4. Influence of porosity on energy absorbed for Al + Cu mixtures.

Compacting was performed on Al + Fe, Al + Cu, and Al + Zn mixtures. Figure 1 presents compaction curves for the pure Al and Zn powders and their mixtures. As the Zn content of Al is increased, the curves rise higher. The same is observed also in the case of Cu and Fe added to Al.

The effect of porosity on specific work for pure Al and Zn powders and their mixtures is illustrated in Fig. 2. As the amount of Zn in Al is increased, the curves drop lower and lower, while the curve for pure Zn occupies the lowest position. However, the curve for pure Al does not fit into this general pattern. In Figs. 3 and 4 is shown the effect of porosity on the amount of energy absorbed for Al + Zn and Al + Cu mixtures. An analogous relationship is observed also for Al + Fe mixtures.

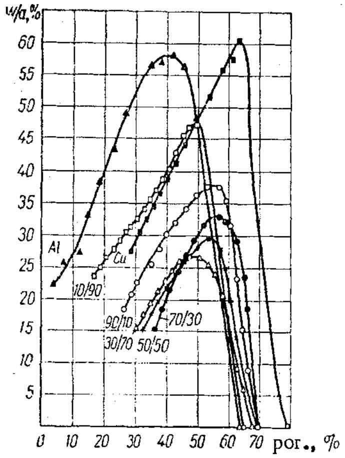


Fig. 5

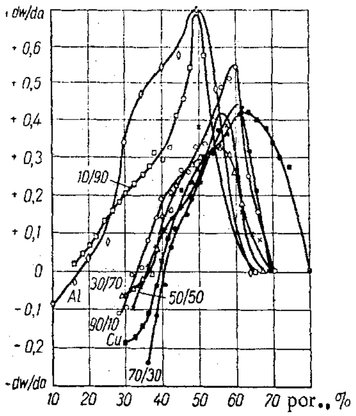


Fig. 6

Fig. 5. Integral relative energy absorption for Al + Cu mixtures.

Fig. 6. Differential relative energy absorption for Al + Cu mixtures.

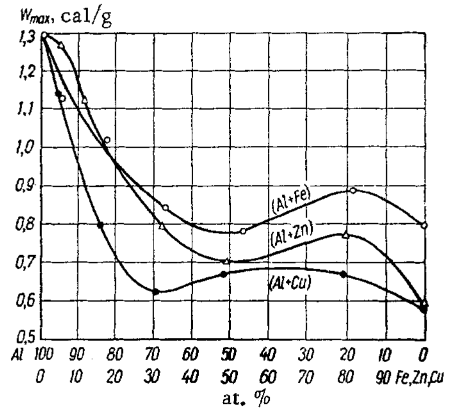


Fig. 7. Dependence of maximum energy absorption on concentration for Al + Fe, Al + Zn, and Al + Cu mixtures.

Figure 5 shows integral relative energy absorption at individual stages of compaction of Al + Cu mixtures. Differential relative absorption in the compaction of Al + Cu mixtures is illustrated in Fig. 6. Here, as for homogeneous powders [1], relative absorption passes through a maximum at a certain density, which is evidently linked with a strength loss of the material at high degrees of densification.

The energy discharge accompanying the strength loss of the material shows up particularly clearly on curves of differential relative absorption. At high degrees of densification, differential absorption in individual stages of compaction becomes negative. This indicates that, at such degrees of densification, the amount of heat liberated is greater than the work of deformation. Such a phenomenon can only take place when the energy stored up by the lattice in the preceding compaction stages is released.

The presence of a maximum of absolute absorption and the existence of regions of negative differential absorption have already been observed by the authors for homogeneous metal powders [1]. It has now been established that the same phenomena occur also in the compaction of powder mixtures.

Influence of Mixture Concentration on Energy Absorption

The concentration of a mixture very strongly affects energy absorption. Figure 7 shows the dependence of maximum energy absorbed on concentration, in atomic per cent, for Al + Fe, Al + Zn, and Al + Cu mixtures. It will be seen from this figure that, in the compaction of pure Al, substantial energy absorption, attaining a maximum of 1.3 cal/g, is observed.

Cu, Fe, and Zn additions lead to a drop of specific absorption. The most effective in this respect are Cu additions. Energy absorption in this case decreases to 0.62 cal/g (at 30 at.% Cu), i.e., to about 50% of the absorption of pure Al. Let us note that maximum absorption in the compaction of pure Cu is 0.58 cal/g. Fe additions are slightly less effective in lowering the absorption, which decreases to 0.78 cal/g at 50 at.%. Energy absorption in pure Fe is 0.80 cal/g. Zn additions in amounts of up to 20 at.% have a smaller effect on the absorption than the other two elements. At higher concentrations, Zn additions are more effective than Fe in lowering the absorption. This is evidently linked with the fact that the absorption in pure Fe (0.80 cal/g) is greater than in pure Zn (0.59 cal/g). Hence, in order of decreasing capacity for reducing energy absorption, the elements investigated, present in small amounts (up to 10-15 at.%), form the following series: Cu, Fe, and Zn.

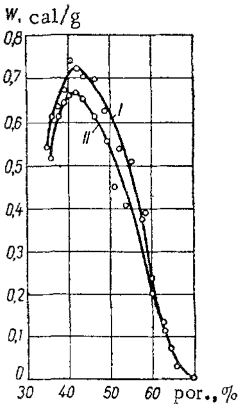


Fig. 8. Dependence of energy absorption on porosity for Al and Cu taken in ratio of 50 : 50 at.% in compaction of separate layers (I) and mixtures (II).

It is interesting to compare these results with data on the influence exerted by the addition of these elements on the electrical conductivity of alloys [3]. Here, the order is reversed. Zn is the most effective and is followed by Fe and, finally, by Cu. It may be assumed that an addition which has less effect on the electrical conductivity of Al, i.e., produces less distortion of the Al lattice, diffuses better into Al during compaction and forms more saturated surface solutions. A decrease in energy absorption is linked with lowered absorptive capacity of these solutions.

Additions of Al to Cu, Zn, and Fe invariably produce increased absorption. This phenomenon is evidently due to the high absorptive capacity of Al.

Let us examine the solubility of additions in Al. Copper is soluble at 550°C in amounts up to 5.6%. With lowering temperature, the solubility drops to 0.03% at 200°C. Solubility at room temperature would be expected to be even less. Iron dissolves in Al at 665°C up to 0.052%. With drop in temperature, the solubility decreases, and at 500°C is less than 0.01% [4]. Zinc is soluble in Al at 100°C up to 1.7 at.%. With decreasing temperature, its solubility sharply drops. As can be seen, all these additions are soluble in Al and are capable of forming solid solutions. Their solubility, however, is low [4].

Next, let us consider the solubility of Al in Zn, Fe, and Cu. The solubility of Al in Zn is low – about 0.1 at.% at room temperature. The solubility of Al in Cu is relatively high – up to 20 at.% at room temperature. Al also dissolves quite extensively in Fe [5]. Thus, formation of surface solid solutions is entirely feasible, since all these mixtures exhibit some solubility of their components at low temperatures.

Energy absorption during the compaction of mixtures is different in character from that occurring during the deformation of alloys. In the latter case [6], energy absorption is enhanced, which is attributed to lattice distortion by foreign atoms. In contrast, energy absorption in the compaction of mixtures is less than for pure metals. This is ascribed to the fact that in mixture compaction materials are formed in the course of pressing, whereas in alloy deformation pre-formed systems are involved.

In the compaction of a mixture, the energy of formation is liberated in the form of heat, which is added to the energy evolved during deformation. Thus, the amount of heat liberated in this case will be more, and the energy absorbed less, than in the deformation of pre-formed alloys. This phenomenon of decreased energy absorption in the compaction of mixtures has been observed in all cases investigated by the authors. It occurs in the compaction of Al + Fe, Al + Cu, and Al + Zn, as well as of Cu + Zn, Cu + Sn, and NaCl +KCl mixtures.

Compaction of Layered Materials and of Mixed Compositions

To show up more clearly the effects of nonmechanical interaction of components, the following two experiments were conducted: in one experiment the components were introduced into the die in the form of separate layers located one above the other, and in the other experiment the components were mixed before compaction. Nonmechanical interaction of the dissimilar components was slight in the former case and substantial in the latter.

We will examine the results obtained for Cu + Al mixtures with component ratios of 70 : 30 and 50 : 50 at.%. Figure 8 illustrates the effects of porosity on energy absorbed for the compaction of Cu and Al layers and of a mixture of these metals. It can be seen from the figure that W_{max} is 0.75 cal/g for the compaction of separate layers and 0.67 cal/g for the compaction of mixtures.

Hence, the reduction in energy absorption is 0.06 cal/g. On the basis of the foregoing considerations, we will take this to be equal to the energy of penetration of atoms in diffusion. Using calculations analogous to those performed in [2], we find that the mean thickness of the surface layer involved in the diffusion process is of the order of 0.4 μ. Such a considerable thickness is apparently due to the low solubility of copper in aluminum. At a given quantity of atoms which have taken part in diffusion, the lower the solubility the greater is the thickness of this layer.

CONCLUSIONS

1. In the compaction of powder mixtures, energy absorption takes place as in the case of pure metals. Relative absorption at first increases, attains a maximum, and then falls off. At high degrees of densification, differential relative absorption becomes negative because of a marked strength loss experienced by materials being compacted.

2. Energy absorption is not an additive function of concentration. This finding is supported by a hypothesis postulating the formation of surface solid solutions in the contact zones of powders being compacted.

3. Additions of Fe, Cu, and Zn in Al lower energy absorption.

4. Additions of Al in Fe, Cu, and Zn increase energy absorption owing to the high absorptive capacity of Al.

5. The thickness of the surface solid-solution layers, as calculated from the drop in energy absorption, is of the order of 0.4 μ.

LITERATURE CITED

1. N. F. Kunin, B. D. Yurchenko, and N. V. Myshkina, Poroshkovaya Met., No. 6 (1964).
2. N. F. Kunin, B. D. Yurchenko, and N. V. Myshkina, Poroshkovaya Met., No. 2 (1966).
3. Machine Design Encyclopedia, Vol. 4 [in Russian], Mashgiz (1947).
4. M. V. Mal'tsev, T. A. Barsukova, and F. A. Borin, Metallography of Nonferrous Metals and Alloys [in Russian], Metallurgizdat (1960).
5. M. Hansen and K. P. Anderko, Constitution of Binary Alloys, McGraw-Hill Book Co., New York (1957).
6. M. A. Bol'shanina and V. E. Panin, Latent Heat of Deformation, Investigations of the Physics of Solids [in Russian], Akademizdat (1967).
7. S. D. Gertsriken and I. Ya. Dekhtyar, Solid-State Diffusion in Metals and Alloys [in Russian], Fizmatizdat (1960).