EXPERIMENTAL MODELING OF THE JOINING OF TWO SUPERFICIALLY MELTED PARTICLES

N. K. Tolochko, V. B. Mikhailov,
N. B. Sobolenko, S. E. Mozzharov,
and I. A. Yadroitsev

The kinetics of surface melting and solidification of particles, and the joining of two superficially melted particles, were studied using model experiments. The experimental results confirmed the welding mechanism of particle joining in laser sintering.

A new trend in powder metallurgy — selective laser sintering of powders — has recently emerged [1-4]. For this reason, the mechanism of contact formation between particles undergoing laser sintering is of particular scientific interest.

In studying the kinetics of laser sintering of real metal powder particles we concluded in [5] that interparticle contacts are formed by a so-called welding mechanism. According to this, particle surfaces melt when exposed to laser irradiation, and, under the influence of capillary forces, join by the formation of liquid interparticle necks, which become solid contacts upon cooling. Investigation of the nature of these processes is of paramount importance; however, their direct observation in real powders is very difficult. Therefore, we have attempted to experimentally model the indicated processes.

The present work considers the laws governing the rate of progression of a liquid front from the surface into the interior of an externally heated body, and also those governing the movement of the solidification front upon subsequent cooling; the laws governing particle joining at various degrees of surface melting; the hydrodynamics of the molten surfaces in particle joining.

Melting and Solidification of Particle Surfaces. The experimental method was as follows: The specimen investigated was a small portion of the surface layers of a body (particles) included within a narrow sector and nominally separated from the main body. It was assumed that the melting and solidification processes were the same over the entire surface as in the selected portion. The model specimen was actually a quantity of preliminarily melted salol, which was placed in a transparent glass tube and subjected to melting and solidification (the phase transformation in this substance occurs at 43°C). The tube (outside diameter 5 mm; inside diameter 3.5 mm; length 60 mm), filled with the model substance, was held vertically. Progress of the melting—solidification front was followed with the aid of an optical microscope, using a measuring rule. In the first series of experiments, in order to initiate surface melting a heat source in the form of a metallic object, electrically heated to a given temperature, was placed in contact with the top end of the tube. In the second series of experiments a laser (LTN-103) beam with an energy density of 40 W/cm² was used as the heat source. Cooling occurred in air at room temperature (after removing the heated object or switching off the laser) in all cases.

Let us consider the results of the first series of experiments. Fig. 1a, shows the time variation of the position of the melting—solidification front at various temperatures T of the contacting heater. The heating time t₀ was chosen to obtain a given molten zone depth. In the initial stage of heating, in which the temperature of the surface layer was relatively low, the melting front moved quite slowly. With increased heating time the rate of movement rapidly accelerated, and after some time again decreased. The rate increased with increasing temperature T. The heat source was removed when a fixed depth of melting was attained (the value of t₀ depended on T). However, in spite of removal of the heat source the melting front continued to progress to a certain depth, which was greater the higher the rate of melting at time t₀ (the depth depended on T). At this depth its progress became much slower. Melting ceased, and the reverse process of solidification began, when thermal equilibrium was established at the phase interface. The extrema in curves 1-3 (Fig. 1a) correspond to the times at which the phase interface reversed its direction.

Fig. 1. Variation with time $t$ of the position of the melting–solidification front for different heating times $t_0$. (a) $T = 60$ (1), 65 (2), and 70°C (3), $x(t_0) = \text{const}$; (b) $T = 65°C = \text{const}$, $t_0(1) > t_0(2) > t_0(3)$; $t_0(4) \to \infty$.

It is important not to allow the particle to melt completely. If this occurs the "welding" mechanism of sintering terminates as such. When $T$ was very high it was necessary to shorten the heating time to allow for the possibility of further progression of the melting front. If, however, $T$ was relatively low, after a certain time of heating a condition of thermal equilibrium was established at the interface between phases. In this case the position of the interface became fixed and independent of the time of further heating (Fig. 1b, curve 4).

Fig. 1b shows the time variation of the position of the melting–solidification front for various durations of surface heating at constant $T$. The depth of melting increased with increasing $t_0$. In addition, the nature of solidification changed. At a certain time after the solidification front began to move from the interface between phases toward the surface an additional solidification front formed at the surface itself, and began to move in the opposite direction. The reason for this is supercooling of the melt at the surface.

As shown in Fig. 2, changing the type of heat source in the second series of experiments did not tend to a significant qualitative change in the results.

**Combined Surface Melting of Particles and Migration of the Surface Molten Layer.** The experimental method was as follows. Circular cardboard disks impregnated with commercial oil were used as model particles. These were located pairwise on the surface of water in a vessel. Rings of the same oil, of as far as possible equal thicknesses, were formed around the disks on the surface of the water. The outside diameter of the rings was maintained constant, while the diameter of the disks was changed in different experiments. In this way it was possible to model various depths of particle melting. The disks played the role of the unmelted solid cores of particles, and the surrounding oil rings of the molten surface layers. Disks in each pair were moved together until the surrounding rings of oil came into contact. At the moment of contact the process of joining was initiated with the aid of a thin needle. This could also occur spontaneously, but only after a certain time