EFFECT OF THE RECOIL PRESSURE INDUCED BY EVAPORATION ON MOTION OF POWDER PARTICLES IN THE LIGHT FIELD DURING LASER CLADDING

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Abstract: A model is proposed, which takes into account acceleration of powder particles by a force induced by recoil of material vapors from the irradiated region of the particle surface. Results of a numerical analysis of heat and mass transfer in the case of motion of individual stainless steel powder particles in a gas flow and in a light field of laser radiation under conditions of laser cladding are presented. Acceleration of particles is found to depend on their diameter, carrier gas velocity, powder material properties, laser radiation power, and degree of attenuation of the power density in the laser beam in the direction of its action on the substrate. The calculated results are compared with experimental data on light-propulsion acceleration of individual particles (of aluminum, aluminum oxide, and graphite) under the action of pulsed laser radiation.

Keywords: laser cladding, powder particles, carrier gas, laser radiation, vapor recoil pressure, light-propulsion motion, modeling.

INTRODUCTION

The laser cladding technology is well known and is widely used in various branches of mechanical engineering, in particular, in recovering worn parts of machines and mechanisms. For instance, the lifetime of heavy vehicle crankshaft parts recovered by the laser cladding method is commensurable with the lifetime of new parts. The cost of recovery is 30–40% of the cost of a new crankshaft.

Laser cladding was studied in numerous publications reviewed in a number of monographs [1, 2]. In particular, the laser engineered net shaping (LENS) technology that ensures production of parts with the shapes close to their final shapes was described in [3]. The LENS technology involves the use of a laser with a power ranging from 500 W to 2 kW for melting the metal powder and obtaining a bulk blank with the density equal to the density of the main material. The metal powder is transported by a powder supply system developed by Optomec, which allows exact controlling of the powder consumption rate. In contrast to other technologies of laser cladding and prototyping, the nozzle in the LENS system is non-coaxial (Fig. 1a): the central nozzle through which laser radiation passes is surrounded by a certain number of gas-powder nozzles.

Figure 1b shows the scheme of the laser-powder head. A typical particle size is 20–80 μm, and the laser beam diameter is 100–600 μm. Supply of the powder material is an important element of the process. The parameters of the gas flow and radiation should be optimized to ensure melting of particles and their impingement onto the substrate in a proper region. The power of laser radiation, its focusing, the radiation energy distribution density...
Fig. 1. Laser cladding process: (a) laser-powder cladding head and processed part; (b) scheme of the laser-powder head; (1) laser beam; (2) particles; (3) substrate; (4) clad layer; (5) protective gas; (6) carrier gas with particles.

in the beam, and the gas and particle consumption rates are the governing parameters controlling the cladding process.

Liu and Lin [4] performed a numerical study of heating of stainless steel powder particles by a defocused beam under conditions similar to coaxial laser cladding. To calculate the motion and heating of a single spherical particle in a carrier gas (argon) flow, they used the known trajectory model supplemented with simple semi-empirical models of melting and heat and mass exchange with the ambient gas, with relations being averaged over the particle size. Their calculations showed that laser heating leads to an increase in the powder temperature as a whole. Evaporation of particles at a high radiation power induces a significant loss of the powder material mass, which may reach 25% for steel particles 20–200 μm in diameter at the radiation power up to 3000 W.

One result of interaction of laser radiation with a gas-powder medium is the reactive motion of particles in the light field. Forces induced by the presence of a light source can be sufficiently large and affect the motion of small particles in various media. The motion of particles in powerful laser beams has been studied since the 1960s when the first lasers appeared. The motion of particles can be induced by the action of light pressure and also by reactive and photophoretic forces. The emergence of reactive and photophoretic forces is caused by nonuniform heating of the particle surface by the laser beam [5].

Askar’yan et al. [6] formulated a problem of light-propulsion acceleration of macroscopic particles with the size of the order of 0.1 mm to velocities of $10^4$ to $10^5$ m/s. Particles of metal chips and corundum powder placed into the field of radiation of a ruby laser were used in those experiments. It was shown that the recoil pressure due to evaporation exceeds the light pressure by three or four orders of magnitude and ensures laser acceleration of particles under standard conditions.

Waniek and Jannuz [7] studied the possibility of acceleration of charged particles due to surface evaporation in the presence of powerful laser radiation. Aluminum particles 25 μm in diameter freely suspended in a time-dependent electric field possessing focusing properties were located inside a focal spot 100 μm in diameter, which was generated by a standard ruby laser with a power density of $10^{10}$ W/m² and energy of the order of 0.1 J. Laser pulses contributed to staged acceleration of particles and simultaneously provided a possibility of visualizing particle trajectories. Velocities of the order of 200 m/s were obtained owing to the recoil pressure generated by material evaporation; the velocity direction coincided with the beam direction. The results satisfy the momentum conservation law with partial evaporation of the particle material taken into account.

Goela and Green [8] reported the results of a theoretical analysis of ablative acceleration of small-size diamond particles (from 25 μm to 1 mm) to extremely high velocities (about $10^5$ m/s) with the use of super-powerful laser radiation (power density greater than $10^{13}$ W/m²). They demonstrated that particle rotation is