Reaction coatings on metals by laser processing

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Chapter 6
Summary and Outlook

Summary — At the start of this thesis work, two goals were formulated: apply a ceramic coating on aluminum alloys by laser processing for practical purpose, and subsequently try to understand the physical nature of bonding at the metal-ceramic interfaces. The first aim was realized by means of a **reaction coating** technique. In the reaction coating processes, the exothermic heat from the chemical reactions plays a predominate role in obtaining a thick and homogeneous ceramic layer on aluminum alloys. The second aim has been approached along two separate routes: a study of wetting process of liquid metals on ceramic substrate and a microscopic study of metal-ceramic interfaces.

In this thesis, the wetting phenomena in a metal-ceramic system have been systematically investigated, focusing on the following four aspects: wetting kinetics, effect of surface roughness on contact angles, wetting irreversibility and reactive wetting. In the study of **wetting kinetics**, a surface diffusion model has been developed which can describe the spreading of a liquid metal on a ceramic substrate, whereas a hydrodynamic model (viscosity effect due to volume diffusion of liquid) is only suitable for a liquid polymer spreading on a solid substrate. In the study of the influence of **surface roughness** on contact angles, a quantitative relationship between surface roughness parameters and contact angles derived, which is correlated rather well with our experimental measurements. Further, an important physical phenomenon of **wetting irreversibility** in metal-ceramic system has been observed. The mechanism for this wetting irreversibility has been proposed on the bases of chemical bonds built up at metal-ceramic interfaces. It is stated that many phenomena in the field of metal-ceramic interface could be interpreted based on this wetting irreversibility. Finally, an important process of **reactive wetting** in metal-ceramic system has been studied. The mechanism has been successfully established, where a **volume criterion** of ceramic substrate during reaction was proposed: if the substrate volume increases the wettability is improved by the chemical reaction, otherwise it is not.

As far as the interplay between interface structure and mechanical behavior is concerned, a simple model to correlate an **interface strength** with contact angle (or the work of adhesion) is suggested. According to the observations by the transmission electron microscopy and high resolution electron microscopy, two types of interface structures have been observed in the ceramic coated aluminum alloys, which are **mullite/Al** in the coating of

SiO_2 and γ-Al_2O_3/Al in the coating of Cr_2O_3. These mullite/Al and γ-Al_2O_3/Al interface structures turn out to be important in keeping the metal-ceramic interface firmly bonded after a rapid cooling from high temperatures during laser processing.

Outlook — (1) The experimental approach to quantify the interface properties between metal and ceramic, such as interface strength, fracture toughness and work of adhesion, is not well developed up to now. A four-point bending test turns out to be a useful method for the measurement of interface toughness. However it is not suitable for the strong metal-ceramic interface as the plastic deformation of metals may absorb most of the energy for initiating an interface crack. More attempts are required in this field. During this thesis work, some experimental works have been attempted, for instance, an interface pre-crack was first prepared by a micro-hardness notch and then the sample was quenched into a liquid nitrogen to introduce a high thermal stress at the interface which may lead to the propagation of the pre-crack. However, as a water layer always exists between liquid nitrogen and quenched samples, the cooling rate is not sufficient for the pre-crack to propagate.

(2) It has been noticed from experiments that a complex and non-stoichiometric oxide such as mullite and spinel may promote adhesion of interface. However, theoretical calculations have not been done yet. It would be worthwhile to carry out some scientific work on the bases of interface electronic structure aspect of metal-ceramic interface as a function of the chemical composition.

(3) In-situ observation at high temperatures at a microscopic scale (smaller than 1 μm) may provide some insight about the wetting process of liquid metals on ceramic substrates. This requires a high temperature scanning electron microscope. The volume criterion of ceramics during a chemical reaction may apply to a more general situation of chemical reaction in which a volume increment corresponds to a diffusion-controlled mechanism but a volume decrease may relate to a reaction-controled process.