Chapter 11
Trend and Development in Laser Surface Modification for Enhanced Materials Properties

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ABSTRACT

This article presents a process review of the commonly available laser surface modification techniques for surface property enhancement. This is reinforced with the specific case treatment of research trends in relation to commonly treated materials. The progression from simple surface modification to the production of components with multifunctional characteristics known as functionally graded material is discussed in combination with emerging research focus on the computational simulation of laser surface modification for optimization of process dynamics.

1. INTRODUCTION

Many solid materials possess adequate bulk mechanical properties which commend them for a number of applications but this is not usually the case with their surface properties. In most cases, the bulk material lacks good surface characteristics for effective performance for the timescale over which it is presumed fit-for-purpose. Additionally, literature (Krauss, 1992) indicates that surfaces of materials are subjected to greater stresses and more direct environmental impact than the interior; hence, when such aggressive stresses reached a material's resistance limit, surface initiated fracture, fatigue, wear and corrosion failures occur. Therefore, surfaces of materials are usually twitched to make them robust to the environment in which they will be used in order to derive maximum benefit. The process of treating the surface of materials to improve their surface functionalities and making them robust to their environment is referred to as surface modification or surface engineering. The process involves treatment of the surface or near-surface regions of a material to permit the surface to perform functions that are distinct from those demanded

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from the bulk materials (ASM International, 2001; Cotell and Sprague, 1994). Surface modification has a chequered history from the advent of civilization to the present age and it manifests in many forms; but irrespective of the form, however, it involves changing the composition, crystal structure, texture, chemistry and microstructure of the substrate of the bulk material up to certain depth towards creating new features and properties in the surface (Burakowski and Wierzchon, 1999). Some of the benefits of surface modification include improved corrosion and oxidation resistance, improved wear resistance, reduced frictional energy loss, improved fatigue resistance, enhanced electrical/electronic properties, thermal insulation, size restoration, biomedical functionalization, and improving aesthetics (Ansari et al., 2014). Because the motivation for surface modification is very wide so is the spread of the process very wide as well. At one end of the wide spectrum, the depth of modified surface could be very thin between 0.001-1.0 mm and at the other end, overlayer surface depth in the range 1- 20 mm are typical (Krauss, 1992). These modification depths are, of course, process specific and thus, each process can only optimise within a specific length scale range. There are several presentations of the process such as ion implantation, nitriding, aluminising, physical vapour deposition (PVD), chemical vapour deposition (CVD), anodising, laser processing, thermal spraying, cold spraying, and liquid deposition methods. The possible range of modification depth in these processes is shown in Figure 1 with ion implantation providing the smallest depth while weld overlay could be in the tens of a millimetre.

Among these several processes, laser surface modification particularly laser deposition has the capacity to provide across the spectrum range (nano to millimetre) of modified surface depth not possible through other processes. Arising from these possibilities which have resulted in a wide range of improved surface properties in treated materials, the growth in laser surface modification process has been exponential in the last three decades; and new application areas are equally emerging (Baker 2010). The process is one of the strong driving forces advancing additive manufacturing particularly in laser engineered net shaping (LENS) manufacturing systems (Gu et al., 2012).

The attraction in laser technology for surface modification is driven by the ability to precisely control the spot onto which the beam is delivered to achieve the desired response. In specifics, laser beam has the ability to precisely deposit a large amount of energy into a material over a short time scale in a spatially confined region near the surface of the material. This permits the control of local surface properties relative to the bulk materials and other regions on the surface (Brown and Arnold, 2010). The degree of distortion and size variations in laser modified layers is minimal compared to such other processes such as weld overlays or conversion coating. The change in composition and structural fluctuation is equally less compared to thermal surface treatment. Furthermore, it provides excellent interfacial bonding between the top layer and the substrate layer resulting in a strongly adherent surface modified layer. Ultimately, it provides possibility for the formation of novel surface alloys not possible with the other processes owing to the non-equilibrium characteristics of the process (Kwok et al., 2000). Thus, the many possibilities of materials response from the effect of the incident laser energy, the interaction time scale and other laser parameters that can result in changes spanning multiple length scales, from the atomic to the macroscale, have been responsible for the growth in laser surface technology.

There exist extensive literature on several aspects of laser principles, laser surface modification and applications which are not integrated but are far and wide apart (Dahotre, 1998; Steen, 2003; Ion, 2005). It has been very difficult and near impossible to aggregate these wide publications on laser and its use for surface modification into a simple, quick but detailed reference guide containing recent developments in the process. Therefore, this article attempts to provide in a single piece, basic generic information on laser surface modification reinforced with several reported works on some materials. While it is not