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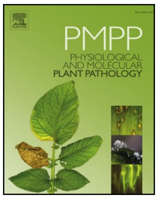

Review

Review: Laser shock peening as post welding treatment technique

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ABSTRACT

Laser shock peening (LSP) is a modern and efficient thermo-mechanical approach to engineer and modify the surface and subsurface related properties of materials which has been frequently opted by contemporary researchers in the field of peening. The main objective of this review article is to emphasize LSP as a post weld treatment method which may help in the commercialization of LSP which is considered a challenge till date. Combining laser welding and laser shock peening could be an alternative and promising approach for improving weld quality over different conventional methods of post weld treatments. With this hindsight, reports incorporating welding and peening in last decades are reviewed. The notable effects of LSP on the mechanical properties and microstructure of different weldments are also discussed along with the classification and important parameters of LSP. We conclude that LSP can indeed be used as an effective post weld treatment (PWT) method in industrial manufacturing process.

1. Introduction

A sub-type of surface engineering and modification process used to impart beneficial compressive residual stress at and near the surface of metallic components by using high energy laser beam is called laser shock peening (LSP). The deep (of the order of mm) and large compressive residual stresses (several hundreds of MPa) induced by LSP increases the resistance of the materials to surface-dependent failures such as fatigue and fretting fatigue by delaying the crack initiation time and its propagation. In the following, we trace the key events in the history of surface modification processes in general, leading in particular to the establishment of LSP as a dominant process. If we consider the facts of human civilization in different eras of ancient time, we can notice their never ending attempts to improve the quality of the materials in daily life. From armour to weapons and tools to vehicles everything needed constant improvement for their better lifecycles and benefits [1]. In this pursuit, different methods like hammering, rolling, burnishing and peening were developed to modify the associated properties (mechanical, metallurgical and microstructural). In some literature these methods are also highlighted as methods for pre-stressing the materials since they subject the materials under stressed state by inducing residual stresses [2]. The residual stresses are of two types: tensile and compressive. Tensile residual stress is detrimental (since it can accelerate the rate of failure mechanisms like ‘pure’ mechanical fatigue and corrosion fatigue) while compressive residual stress is beneficial (since it can decelerate the failure mechanisms).

The surface modification field was broadly dominated by the methods like hammering, burnishing and rolling before the idea of peening was introduced. In the decade of 1920s the concept of shot peening (initially termed as shot blasting) was developed while searching suitable methods to clean steel. Researchers of that period noticed that shot blasting cleaning of valve springs, connecting rods, steering arms and knuckles, axle shafts, gears and pinions resulted in longer life and higher resistance to fatigue and was adopted in automotive industry [1]. It is also reported that during the time of World War-II, shot peening was applied in armour and aircraft industry to enhance the strength and durability of machinery components used for making weapons and aircrafts [1]. By the decades of 1950s shot peening was established as one of the accepted processes of metallurgy and also appeared in the literature of applied Physics. Shot peening was dominant over other methods of inducing compressive residual stress (CRS) at and near the surface of metallic components for more than six decades with some obvious merits and demerits. The expanding research was going on in one direction with the generation of number of research articles and patents related to shot peening and in another direction with invention of pulsed laser technology in the decades of 1960s, seeking its application in improving material strength. The major breakthrough occurred in late1960s when Anderholm [3] at Sandia Laboratories, Albuquerque, New Mexico discovered that much higher plasma pressures (developed due to material-laser interaction and useful in creating CRS) could be achieved by confining the expanding plasma against the target surface. Subsequently Anderholm and Boade [4] confined the plasma by placing a quartz overlay, transparent to the laser beam, firmly against the target surface. Their

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method of confining the plasma greatly increased the resulting pressure with generation of pressure peaks of 1 to 8 GPa, over an order of magnitude greater than unconfined plasma pressure. During1970s researchers from BCL (Battelle Columbus Laboratories, USA) studied the practical utilization of laser generated stress waves for processing of materials and its effects on mechanical and microstructural aspects of materials [5,6]. Similarly Fabbro et al. [7,8], Devaux et al. [9], Berthe et al. [10,11] and Peyre et al. [12,13] at LALP (Laboratoire d' Application des Lasers de Puissance) in France extensively studied the nature of laser produced plasma in confined geometry with different process parameters and contributed more for deeper understanding of basic Physics behind LSP process, thereby establishing LSP process as an emerging field of applied research in modern metallurgy.

Different grades of material like Steel [14–16], Titanium [17–22], Aluminium [6,23], Copper [24], Magnesium [25–27], Super Alloys [28,29], and Bulk metallic glasses [30] have been successfully peened in the past and its beneficial effects are discussed by various researchers. Most of the researchers have performed independent and comparative study of LSP process with other conventional methods of peening like shot peening (SP) [31,32], ultrasonic impact peening (UIP) [33,34], oil jet peening (OJP) [35] and water jet peening (WJP) [36–38] and it has been found that LSP is significantly better in terms of depth of induced CRS layer, surface roughness and reliability compared to conventional methods of peening. If we are concerned about peening process the most important factor is residual stress. The other mechanical and microstructural property of peened specimen highly depends on residual stress. This fact helps us to understand that LSP process can be a better approach for minimizing surface related failures of the metallic components where tensile residual stress is high and detrimental. As we know, this kind of situation is mostly present at and around the welded joints of weldment because of restricted expansion and contraction during heating and cooling cycle of welding, respectively. Different researchers have performed the peening on welded specimen and have characterized its effects on weldments with some notable improvements as listed in Table 1.

If we closely observe the trend of research in the field of LSP process, only academic research is dominating and its industrialization still seems to be a challenge. Therefore the most essential step in this field is its initiation toward rapid industrialization, for which idea of 'combined welding and peening' may be anticipated as a promising one. In the context of welding even single automobile and aircraft unit contains minimum 1000–2000 welded spots and most of them are at very crucial parts with very crucial roles. It would be better in term of longer and promising service life, if one can treat the surfaces containing welded regions by opting laser shock peening before putting them in operation. At the same time very feeble literature is available in the context of laser shock peening of weldment and there is no specific review article particularly about the laser shock peening of weldments. Different researchers have reviewed in the past about welding [39–56] and peening [8,57–63] and have covered most of the concepts in welding and peening. Therefore, in this work our attempt will be focused mainly on filling that gap appearing in the interesting field of laser shock peening by an extensive review including various aspects of welding and LSP.

2. Laser beam welding (LBW) and its advantages over conventional welding

Welding is a very complex process with very difficult configurations to understand. One can derive the process overview, process parameters, background of welding (especially laser beam welding) and different problems encountered while welding and their solutions from the literature [48,64–70]. Welding may be defined as 'melting followed by joining'; however in reality it is quiet complicated. Even though melting, joining and solidification all happens in very short duration of time, weldment undergoes various mechanical, thermal, metallurgical and microstructural changes. Apart from this, evaporation of alloying elements while welding and duration, types and conditions of ageing after welding also play an important role in determining the quality of weldment. The effect of welding can alter properties of weldment far from base material involving complex interaction of thermal, mechanical and metallurgical phenomena, resulting in poor and unexpected weld qualities. In welding, thermo-mechanical interactions combined with metallurgical history result in non-uniform distribution of microstructure in base metal zone (BMZ), heat affected zone (HAZ) and fusion zone (FZ).

Laser beam welding has gained popularity due to various advantages over conventional methods (GTA or GMA welding, TIG welding, FSW etc.) such as narrow heat affected zone (HAZ), fine grained weld zone, better and static mechanical properties, substantially higher weld speed, cost reduction, contactless interaction with work piece and symmetric weld geometry of the weldment [65,70].

Even though laser beam welding is capable of producing good quality weldment, sometimes hybrid structures are needed in aircraft, aerospace and automotive industries and hence different combination of materials are needed to be welded. This is a very difficult technological task because of important mismatch in physical properties, limited mutual solubility and formation of intermetallic phases which eventually results in commonly encountered defects like hot cracking, porosity and softening(weakening) of fusion zone [66]. Post weld heat treatment (conventional approach of strengthening and relieving stress from weldment) may improve the strength of fusion zone but cannot be recovered similar to the base material and is limited to certain heat treatable materials only [71]. So in upcoming sections we discuss LSP as an alternative approach of post weld treatment for laser weldments.

3. Process overview, classification and important parameters of LSP

The process overview of laser shock peening in extensive way is already available in literature [59,61] including research articles from our group [15,16,28,29,72–77]. So we discuss in this section about the process overview in brief followed by the classification of LSP (which is not discussed in any other reviews till date) and its major parameters.

3.1. Process overview of laser shock peening

The schematic diagram of laser shock peening process is shown in Fig. 1. When the laser is triggered, it passes through the transparent overlay (confining medium) and reaches to the surface to be peened, covered by opaque layer or sacrificial layer. The continued delivery of laser pulses rapidly heats and ionizes the vaporized material, converting into rapidly expanding plasma. Meanwhile the pressure exerted by expanding plasma in between confining medium and target surface, enters the target surface as a high amplitude shock wave. If the amplitude of the shock wave is above the Hugoniot elastic limit (HEL) of the target, the material deforms plastically during the passage of shock waves and results in generation of compressive residual stresses below the target surface. The magnitude of compressive residual stress is highest at or immediate below the surface and varies as a function of depth.

3.2. Classification of laser shock peening

From the beginning of development and invention of peening itself, new methods and their modifications have evolved (in both conventional and modern peening) at different times. As a result today we have around half dozen methods available for peening, most of them being more or less equally effective with unique and significant benefits and limitations. Even though the principle involved remains same, the laser shock peening is classified on the basis of surface condition of sample (to be peened) and surrounding temperature and same is