Introducing Gradient Severe Shot Peening as a Novel Mechanical Surface Treatment

This article is based on the open access paper by Erfan Maleki[1,4], Sara Bagherifard[1], Okan Unal[2], Michele Bandini[3], Gholam Hossein Farrahi[4,5] and Mario Guagliano[1] (2022), Scientific Reports, Vol. 11 (1), 22035.
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SHOT PEENING is widely used for improving mechanical properties especially fatigue behavior of metallic components by inducing surface hardening, compressive residual stresses and surface grain refinement. In air blast shot peening, projection pressure and surface coverage (an index of peening duration) have been considered as major controlling process parameters; the combination of these parameters plays a critical role in the beneficial effects of shot peening. Generally in severe shot peening aimed at obtaining surface grain refinement, constant values of pressure are considered with different peening durations.

Considering very high peening duration, however, the phenomenon of over shot peening, which can be identified with the formation of surface defects could occur. The present study introduces a novel shot peening treatment, here called gradient severe shot peening (GSSP) that instead of using constant projection pressure, implements gradually increasing or decreasing pressures. The gradual increase of the projection pressure acts as a pre-hardening stage for the following higher projection pressure boosting the potential of the material to tolerate the sequential impacts and thus become less prone to the formation of surface defects.

The results of the experiments indicate significant fatigue life improvement obtained for GSSP treated specimens compared to the standard treatment with constant pressure. GSSP avoids the detrimental effects of over-peening, while maintaining the beneficial effects of surface nano-crystallization, surface hardening and compressive residual stresses. The notable difference in fatigue strength enhancement for GSSP treated material can be also attributed to the modulated surface morphology with lower surface roughness compared to a standard shot peening treatment with the same exposure time.

Initially presented in 1940[1], shot peening (SP) is a cold working process in which the surface of the target material is bombarded by impacts of small shots under controlled conditions[2]. This simple and cost-effective process is widely used for improving the mechanical properties of metallic materials such as fatigue, wear, corrosion, etc.[3–6]. Schematic illustration of an air blast SP equipment is shown in Fig. 1a. (Page 20) Variation of peening duration can alter the control parameter of surface coverage; coverage is defined as the ratio between the area that is plastically deformed by the impact to the total exposed area[7].

On the other hand, using a regulator and solenoid valve, the projection pressure of SP process can be controlled to regulate the velocity of the impacting shots and thus the kinetic energy of the shot stream; these are associated with another main control parameter called Almen intensity[8,9]. Figure 1b, c schematically presents the effects of peening duration and projection pressure on the surface of the target material. The kinetic energy of the SP treatment is defined by the mass and velocity of the impacting media. In air blast SP process, high impact velocities can be obtained by increasing the projection pressure or using larger shots[5,10].

In addition, increasing the peening duration will increase the number of the impacting shots on the target leading to higher kinetic energy transmitted to the substrate[11–15]. SP induces surface layer grain refinement and hardening as well as compressive residual stresses in the surface layer of the treated material[16]. However, due to the shot impacts and the generated dimple shaped indents, the surface morphology of the shot peened material changes leading to higher surface roughness[17,18]. Schematic illustration of surface roughness variation, grain refinement, surface layer hardening and induced compressive residual stresses are presented in Fig. 1d.

It has been reported that by increasing the Almen intensity and surface coverage and accordingly raising the kinetic energy of the SP treatment compared to the ones used in the conventional shot peening (CSP), so called severe shot peening (SSP) or high energy shot peening (HESP) processes

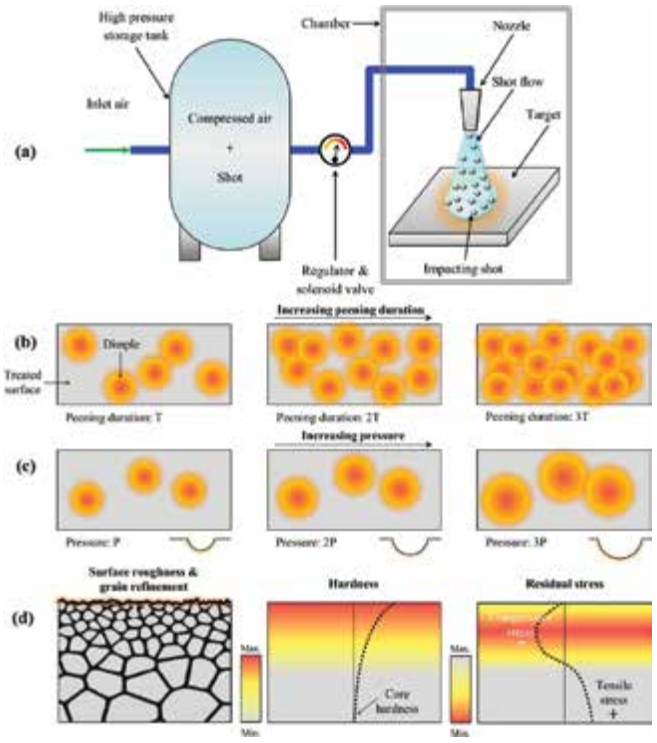

Figure 1. Schematic illustration of (a) air blast SP equipment, effects of SP treatments in terms of increasing the (b) peening duration and (c) projection pressure on the target surface (d) common effects of SP treatment on increasing the surface roughness and inducing surface layer grain refinement, hardening and inducing compressive residual stresses, from left to right.

can be obtained[19,20,21]. SSP generated nano-structured grains on the surface layer[22] and induces higher compressive residual stresses[23]. In addition, SSP was reported to have more beneficial effects compared to CSP in terms of mechanical properties and fatigue behavior improvements, when applied with optimized parameters[24,25,26,27,28,29,30].

However, it was found that by using higher intensities and coverages than the ones considered in SSP, over shot peening (OSP) phenomenon appears. Although, in OSP higher surface hardening and higher compressive residual stresses can be achieved but due to the very high kinetic energy of the shot impacts, multiple surface defects including nano/micro-cracks, and overlaps can form on the treated surface[31]. These defects have high detrimental effects on mechanical properties of the SP treated material, often leading to fatigue strength reduction[32,33,34,35,36,37,38,39].

Figure 2a presents the schematic illustration of different categories of CSP, SSP and OSP processes considering peening duration and projection pressure.

In this study, a novel type of SP, here called gradient severe shot peening (GSSP) is presented for the first time, to the best of the authors' knowledge. In GSSP, instead of

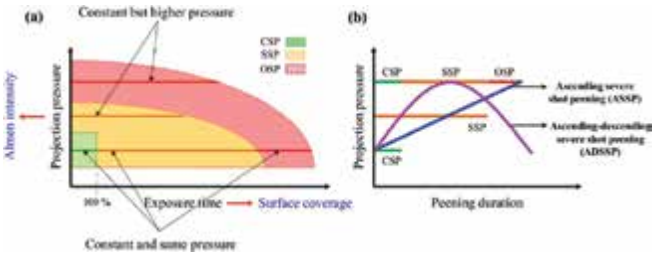

Figure 2. Schematic illustration representing (a) the comparsion of CSP, SSP and OSP in terms of projection pressure and peening duration and (b) variations of projection pressure through the peening duration in novel GSSP treatments of ASSP and ADSSP compared to CSP, SSP and OSP treatments.

using a constant projection pressure, variant pressures are considered. Herein, two different GSSP processes of ascending severe shot peening (ASSP) and ascending-descending severe shot peening (ADSSP) are introduced based on the trends considered for variation of pressure.

The schematic comparisons of the newly presented treatments with standard categories are depicted in Fig. 2b. The projection pressure in ASSP is continuously ascending while in ADSSP it gradually increases to reach a maximum value and then decreases. In these two processes, the detrimental effects of OSP are avoided, while maintaining the beneficial effects of surface nano-crystallization, surface hardening and compressive residual stresses.

The material considered for the investigations is Inconel 718 that is a nickel super-alloy. Inconel 718 has lots of application in different industries such as aviation and aerospace, etc. due its excellent mechanical strength and properties[40,41]. However, surface processing of Ni-based superalloys in particular with mechanical surface treatments is a challenging procedure[42,43,44].

Comprehensive experimental analyses in terms of micro structural characterization, roughness, microhardness and residual stresses measurements as well as axial fatigue tests are performed to compare different categories of treatments based on SP.

Editor's Note: According to Michele Bandini with Peen Service, this project is part of wider research work on several materials. Peen Service has been cooperating with Politecnico di Milano for over 25 years on several aspects of the peening process, looking continuously for new applications and better improvements.

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