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A CRITICAL ANALYSIS OF SHOT PEENING AND ITS IMPACT ON ENHANCING FATIGUE STRENGTH

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ABSTRACT

This study focuses on the shot peening (SP) process, which is used to improve surface characteristics. This paper provides coverage of the basic use of Shot peening processes and explores their many applications; also it provides a comprehensive analysis of the different materials used in metallic structures, along with a detailed examination of the surface layer properties shown by these materials. This paper examines the benefits of using the process of surface polishing in various materials, focusing on its ability to improve surface hardness and roughness. The examination of optimizing Shot Peening is conducted to discover the significant aspects that influence its quality. This paper presents an overview of the applications of shot peening in different sectors, with a particular focus on the field of medicine. Several research investigations have shown that the process of shot peening (SP) induces residual compressive stresses inside the materials, hence promoting the development of surface layer characteristics. This review research encompasses an examination of the criteria pertaining to surface property as well as an exploration of several ways of evolution.

KEYWORDS: surface quality, optimization, residual compressive stresses, roughness, hardness.

Introduction

To resist crack propagation [1] in the surface, SP [2] is employed by bombardment of the surface with hard shot [3]. It has been demonstrated that SP is a useful technique for boosting material resistance [4] to several type of stress induced damage [5], notably damage brought in by cyclic loading [6]. SP is increasingly being employed in many industrial fields [7-9], especially in the aerospace industry [10] and biomedical [11-13], because it can be applied to broad variety of structural components regardless of the shape [14]. SP will enhance the fatigue strength [15] of the highly stressed automotive parts [16] resulting higher performance with increased strength [17]. While SP treatments improve the effect of surface defects [18], they also have few drawbacks like enhancement of surface roughness as shown in Fig.1. SP process has many important variables [19] and that should be chosen with the utmost care. The poor choice of the variables may degrade

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the fatigue performance of SP [20]. Hence a thorough knowledge about the effects of SP might lead to an improvement of the process in terms of fatigue resistance. This review paper's goal is to examine SP's advantages for enhancing the components needed for diverse industrial applications. Also, it covers the numerous techniques for enhancing the materials' fatigue strength as well as the factors that affect that strength. Fig. 2 displays a schematic representation of SP.

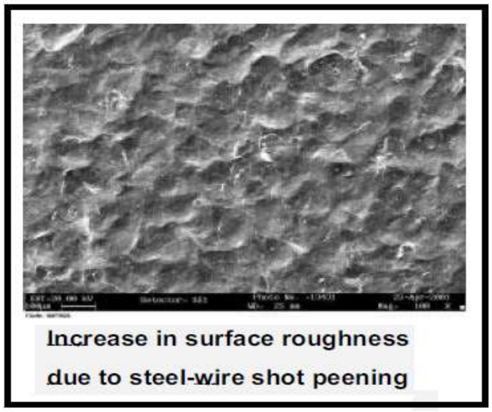

Fig.1. Examples of surface damage produced by shot peening

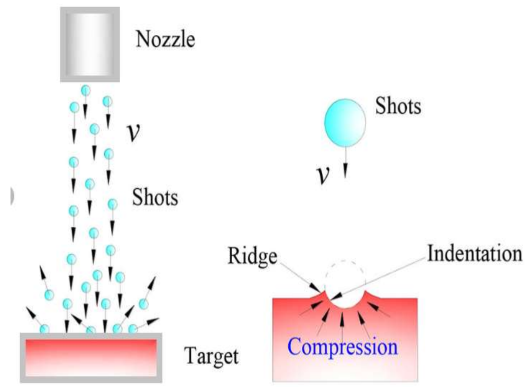

Fig.2. Schematic diagram of shot peening

T5-treated high-strength magnesium alloy ZK60's surface properties and high cycle fatigue (HCF) performance were examined by Lie et al [21]. They performed SP using glass beads with an average diameter of 0.35 mm and an Almen intensity range of 0.02 to 0.40 mmN. Their study suggested that SP significantly alters the surface microstructure and texture of ZK60-T5, producing residual compressive stress in the surface deformation layer. The ZK60-T5 magnesium alloy exhibits a noticeable over peening effect. Before and after SP, the surface characteristics of (TiB + TiC)/Ti-6Al-4V were examined by Xie et al [22]. The findings demonstrate that higher reinforcement levels and more intense SP reduce surface roughness. SP intensifies compressive residual stresses and hardness, which is primarily caused by plastic deformation and a high dislocation density in the near surface layer. They also claim that the higher compressive residual stresses and hardness following a suitable SP treatment are advantageous for industrial applications. The stress formation during SP is presented in Fig.3.

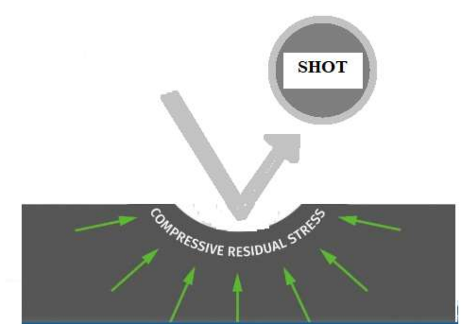

Fig.3. Stress formation during shot peening process [35]

Medical equipment composed of 17-4 PH stainless steel is thought to be appropriate for additive manufacturing when the surface is modified by SP. Walczak et al. [23] looked into the effect of SP on the surface texture, corrosion, and wear performance of 17-4PH steel fabricated by direct metal laser sintering (DMLS) additive manufacturing. The biggest improvement in surface hardening, or around 119% (from 247 to 542 HV), was seen in 17-4 PH specimens peened with steel and ceramic shots, which greatly increased their wear resistance. Their findings showed that employing ceramic beads for SP caused the material's grain size to be refined from 22.0 to 14.6 nm and its surface morphology to be reduced, both of which increased the material's resistance to corrosion. SP of DMLS 17-4PH specimens with ceramic beads at 0.6 MPa pressure produced the best surface shape, toughness, and structure, which enhanced corrosion and wear resistance. The surface structure's condition and biomedical applications are crucial factors in the effective insertion of prostheses like bone replacement, which are currently created increasingly using DMLS technology. Żebrowski et al. [24] examined "the Effect of the SP on surface properties of Ti-6Al-4V alloy produced by means of DMLS technology". The specimens were created with the aid of an EOSINT M280 system, and their surfaces were shot peened using three distinct media—CrNi steel shot, broken nuts, and ceramic balls made of ZrO2—at three separate operating pressures (0.2, 0.3, and 0.4 MPa). They discovered that the process parameters, namely operating pressure during SP and suitable shot selection, would enable the achievement of the qualities with the enhancement of the surface layer necessary for implant equipment.

Surface properties and corrosion behavior of medical grade AISI 316L stainless steel was reported by Ahmed et al. [25]. A common material for the primary hip replacement component is AISI 316L steel. To combat corrosion and fatigue issues, they examined at how SP factors impact surface roughness. Ceramic shots were used for SP, with three different shot diameters (125-250, 450, and 850 m), two different Almen intensities (0.22 and 0.28 mmA), and two different coverage percentages (100 and 200%). By increasing the covering degree and the Almen intensity, the results showed enhanced surface micro hardness and produced compressive stresses. By reducing the contact angle, the rougher surface after shot-peening increased wettability. Lower surface roughness and enhanced corrosion resistance were produced by increasing the shot size. Additionally, they coated the shot-peened surfaces with hydroxyapatite (HA), which enhanced wettability even more. The biocompatible and biodegradable qualities of magnesium alloys make them a good option for temporary biodegradable implants. Magnesium-based materials have a slew of drawbacks, including a fast rate of corrosion and low corrosion resistance. In order to overcome this problem Peral et al. [26] studied the "Effect of warm SP treatments on surface properties and corrosion behavior of AZ31 magnesium alloy". In order to analyze the specimens for grain refinement, surface roughness, work hardening, and residual stresses, AZ31 Mg alloy was subjected to conventional and rigorous SP processes at room temperature, 240 °C (near recrystallization temperature), and 360 °C. To assess the impact of the SP procedures on the specimens' corrosion resistance, potentiodynamic polarization experiments were also carried out. Their findings showed that the most important element influencing corrosion behavior was surface roughness.

2. EXPERIMENTAL PROCEDURE

In their study, Wenxue et al. used the ROSLER VP100BP pneumatic shot peening machine as their chosen equipment for shot peening. The shot peening projectile used in this study is a steel wire cut shot with a diameter of 0.6 mm. It is important to note that the hardness of this projectile exceeds that of the 20CrMnTi material. The pressure of the shot is 0.1 MPa, 0.2 MPa, and 0.3 MPa, respectively. The shot is being sprayed at a right angle to the surface of the specimen, with a distance of 150 mm between the nozzle and the specimen. The shot coverage is 100% and 200%, respectively. The fatigue test was performed using the QBG-100 high-frequency fatigue tester on both the specimens that underwent shot peening and the specimens that did not undergo shot peening. The test specimen underwent axial loading at a frequency of 220 Hz, with a stress ratio of 0.1. The top limit for the number of cycles was defined as 107. The stress ratio, denoted as R, is assigned a value of 0.1 in this study. This choice is motivated by the use of an electromagnetic resonance type high-frequency fatigue tester. It is observed that configuring the stress ratio as positive facilitates the vibration of the tester [27]. The study conducted by Branco et al. [28] extensively examined the impact of various stress ratios on fatigue life. However, it is important to note that the present work specifically concentrates on the influence of shot peening and re-shot peening on residual stress distribution and fatigue life, without delving into the investigation of stress ratio effects. The fatigue experiments were carried out at stress levels of 630 MPa and 700 MPa in order to investigate the impact of shot peening pressure and shot peening coverage on the fatigue endurance. In light of this premise, the specimens that underwent re-shot peening were subjected to fatigue testing at a stress level of 630 MPa. The objective was to examine the impact of the load cycle count on the fatigue life prior to re-shot peening.

3. FATIGUE AND RESIDUAL STRESS

Torres, M.A.S., and Voorwald, H.J.C. [29] examined the fatigue life of AISI 4340 steel and assessed the SP of AISI 4340 steel via formation of a compressive residual stress field (CRSF) in their external surface in order to increase the fatigue life. On the AISI 4340 steel landing gear, rotational bending fatigue tests were performed, and the CRSF was assessed using an X-ray tensometry. It was discovered that the exhaustion process led to the CRSF relaxing. In order to learn more about the crack starting spots, the cracked fatigue specimens were further examined using a scanning electron microscope (SEM). By creating CRSF in solid metals and alloys, ultrasonic shot peening (USSP) is recognized as an efficient surface treatment procedure to improve the mechanical properties of materials [30]. A pre-stressing technique called USSP lengthens the lifespan of mechanical parts. The spheres that make up the shot are propelled by a sonotrode into motion, strike the treated component, and produce a CRSF to get longer fatigue life [31]. Fatigue strength of SAE 9245 steel was improved by Tekeli [32] by the application of SP process. In their work, CRSF produced through distortion stiffening at the surface was created using SP procedure. To completely convert the microstructure to austenite, the samples were heated to 850 °C and maintained there for 20 min. Austenite was then toughened by water quenching. To remove any remaining tensions from the quenching, the specimens were tempered at 500 °C. A variety of fatigue samples, some of which had just been heat-treated and others which had been shot-peened by CS 230 using a high-pressure air gun, were tested on Wöhler fatigue testing machine. Comparisons were made between the fatigue findings for peened and unpeened circumstances. SP has been shown to extend fatigue life by about 30%. Li et al. [33]. analyzed “the effect of micro-SP, conventional shot peening and their combination on fatigue property of EA4T axle steel”. In their investigation, three different SP processes—conventional shot peening (CSP), micro-shot peening (MSP), and dual shot peening (DSP)—were used to test samples of EA4T axle steel. The impacted surface layer was described using the stress distribution, surface finish, morphology, and micro hardness. Their results suggested that the MSP accomplished the greatest surface compressive residual stress (SCRS). While DSP increased micro hardness and SCRS, in their study, it was also revealed severe flaws in the specimens' fatigue strength. There is another method similar to SP for enhancing the fatigue performance and durability of metallic materials is cavitations peening. Soyama et al. [34] studied “the Effect of compressive residual stress introduced by cavitation peening and SP on the improvement of fatigue strength of stainless steel”. They compared Shot and cavitation peening to modify SUS316 L samples, and a displacement regulated plane bending fatigue experiment was used to gauge the samples' fatigue resistance. According to their research, shot peened specimens had a longer fatigue life than cavitation peened samples at bending stresses more than 450 MPa. However, throughout the fatigue testing, CRSF generated by both peening processes decreased. Fig.4. shows the improvement of fatigue strength through SP.

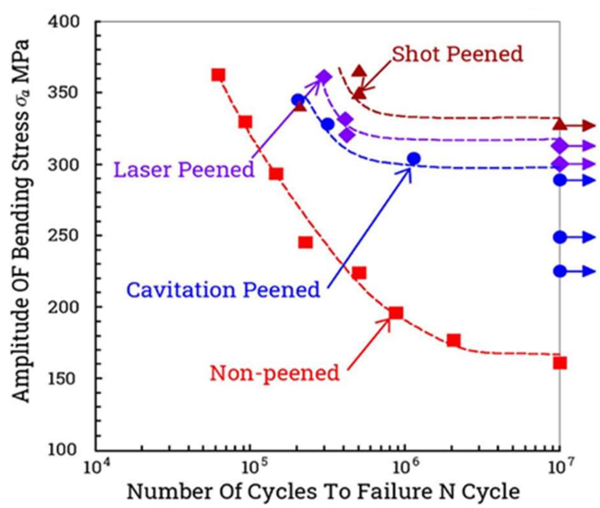

Fig.4.Improvement of fatigue strength through SP

Bagherifard, and Guagliano, [35] studied “the Fatigue behavior of a low-alloy steel with nanostructured surface obtained by severe SP”. They used standard air blast equipment to generate a nanograined layer by applying severe SP to the surfaces of specimens. The treated surfaces of samples have been characterized using a variety of experimental techniques, including microscope inspection, micro - hardness, toughness, and X-ray diffraction studies. The development of a nanocrystallized outer surface is confirmed by their results. . Their results also proved that fatigue life has improved despite the specimen's extremely high surface roughness."The Effect of SP on

Titanium Alloy on Surface Residual Stress and Roughness for Aerospace Applications," according to Kumar et al. [36]. By producing CRSF by SP, they attempted to increase the toughness of the aircraft components and reduce stress corrosion. They used surface and sub-surface residual stresses as well as impact angle, coverage area, and Almen intensity that affect surface roughness as SP factors. To obtain larger residual stress, they used Taguchi's approach for optimizing these parameters.

4.CONCLUSION

The definitions, requirements, theoretical frameworks, practical applications, and ultimately optimized surface coverage approaches derived from the SP process have been comprehensively scrutinised. SP processes offers a diverse assortment of products that are manufactured utilising top-notch components and production methods. The adoption of the SP technique by industry has shown significant promise due to its diverse range of capabilities. Nevertheless, it is essential to acknowledge and tackle many limitations, including the issue of surface hardening, among others. The selection of SP equipment is of significant importance, as it must take into account factors such as component size, shape, and materials. The research revealed that a universally standardised strategy for SP technique does not exist. This study provides an overview of the evolution of several approaches for regulating system characteristics in the context of signal processing. This review study provides an understanding of the needs of surface property and several techniques of evolution.

REFERENCES

1. Qin, Zhi, et al. "Effects of shot peening with different coverage on surface integrity and fatigue crack growth properties of 7B50-T7751 aluminum alloy." *Engineering Failure Analysis* (2021): 106010.
2. Qu, Shengguan, et al. "Effect of shot peening on microstructure and contact fatigue crack growth mechanism of shaft steel." *Materials Chemistry and Physics* 274 (2021): 125116.
3. Segurado, E., F. J. Belzunce, and I. Fernández Pariente. "Effects of low intensity shot peening treatments applied with different types of shots on the fatigue performance of a high-strength steel." *Surface and Coatings Technology* 340 (2018): 25-35.
4. Zhang, Lai-Chang, Liang-Yu Chen, and Liqiang Wang. "Surface modification of titanium and titanium alloys: technologies, developments, and future interests." *Advanced Engineering Materials* 22.5 (2020): 1901258.
5. Song, Jingdong, et al. "Rolling contact fatigue and damage characteristic of AISI 9310 steel with pre-laser shock peening treatment." *International Journal of Fatigue* 155 (2022): 106588.
6. Song, Jingdong, et al. "Rolling contact fatigue and damage characteristic of AISI 9310 steel with pre-laser shock peening treatment." *International Journal of Fatigue* 155 (2022): 106588.
7. Maleki, Erfan, Okan Unal, and Auezhan Amanov. "Novel experimental methods for the determination of the boundaries between conventional, severe and over shot peening processes." *Surfaces and Interfaces* 13 (2018): 233-254.

8. Zhang, Jiyin, et al. "Effects of shot-peening parameters, path, and sequence on residual stress of TC17 alloy." *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* (2022): 09544054221138174.
9. Gan, Jin, et al. "Small–scale experimental investigation of fatigue performance improvement of ship hatch corner with shot peening treatments by considering residual stress relaxation." *Journal of Marine Science and Engineering* 9.4 (2021): 419.
10. Slawik, Sebastian, et al. "Microstructural analysis of selective laser melted Ti6Al4V modified by laser peening and shot peening for enhanced fatigue characteristics." *Materials Characterization* 173 (2021): 110935.
11. Avcu, Y., et al. "Dry sliding wear behaviour of shot peened TI6AL4V alloys at different peening times." *Acta Physica Polonica A* 134 (2018): 349-353.
12. Liu, Huabing, et al. "Microstructure evolution and residual stress distribution of nanostructured Mg-8Gd-3Y alloy induced by severe shot peening." *Surface and Coatings Technology* 404 (2020): 126465.
13. Yıldıran Avcu, Yasemin, et al. "Surface, subsurface and tribological properties of Ti6Al4V alloy shot peened under different parameters." *Materials* 13.19 (2020): 4363.
14. Maleki, Erfan, and Okan Unal. "Fatigue limit prediction and analysis of nano-structured AISI 304 steel by severe shot peening via ANN." *Engineering with Computers* 37.4 (2021): 2663-2678.
15. Maleki, Erfan, et al. "The effects of shot peening, laser shock peening and ultrasonic nanocrystal surface modification on the fatigue strength of Inconel 718." *Materials Science and Engineering: A* 810 (2021): 141029.
16. Prabhakaran, Subramanian, et al. "Residual stress, phase, microstructure and mechanical property studies of ultrafine bainitic steel through laser shock peening." *Optics & Laser Technology* 115 (2019): 447-458.
17. Lu, Jinzhong, et al. "High-performance integrated additive manufacturing with laser shock peening–induced microstructural evolution and improvement in mechanical properties of Ti6Al4V alloy components." *International Journal of Machine Tools and Manufacture* 148 (2020): 103475.
18. Maleki, Erfan, et al. "Introducing gradient severe shot peening as a novel mechanical surface treatment." *Scientific Reports* 11.1 (2021): 1-13.
19. Aguado-Montero, Santiago, et al. "Optimal shot peening residual stress profile for fatigue." *Theoretical and Applied Fracture Mechanics* 116 (2021): 103109.
20. Krishna, L. Rama, et al. "Influence of prior shot peening variables on the fatigue life of micro arc oxidation coated 6061-T6 Al alloy." *International Journal of Fatigue* 106 (2018): 165-174.
21. Liu, W., Dong, J., Zhang, P., Zhai, C. and Ding, W., Effect of shot peening on surface characteristics and fatigue properties of T5-treated ZK60 alloy. *Materials Transactions*, *50*(4), (2009):.791-798.
22. Xie, L., Jiang, C. and Lu, W., The influence of shot peening on the surface properties of (TiB+ TiC)/Ti–6Al–4V. Applied Surface Science, 280, (2013):.981-988.

23. Walczak, M. and Szala, M., 2021. Effect of shot peening on the surface properties, corrosion and wear performance of 17-4PH steel produced by DMLS additive manufacturing. Archives of Civil and Mechanical Engineering, 21(4), (2021):1-20.

24. Żebrowski, R., Walczak, M., Klepka, T. and Pasierbiewicz, K., Effect of the shot peening on surface properties of Ti-6Al-4V alloy produced by means of DMLS technology. *Eksploatacja i Niezawodność*, *21*(1).(2019).

25. Ahmed, A.A., Mhaede, M., Basha, M., Wollmann, M. and Wagner, L., The effect of shot peening parameters and hydroxyapatite coating on surface properties and corrosion behavior of medical grade AISI 316L stainless steel. *Surface and Coatings Technology*, *280*, (2015):.347-358

26. Peral, L.B., Zafra, A., Bagherifard, S., Guagliano, M. and Fernández-Pariente, I., Effect of warm shot peening treatments on surface properties and corrosion behavior of AZ31 magnesium alloy. *Surface and Coatings Technology*, *401*, (2020):126285.

27. Qian W, Wang Y, Liu K, Yin X, He X, Xie L.,Experimental Study on the Effect of Shot Peening and Re-Shot Peening on the Residual Stress Distribution and Fatigue Life of 20CrMnTi. *Coatings*. 13(7) (2023):1210.

28. Branco, R.; Costa, J.D.; Borrego, L.P.; Wu, S.C.; Long, X.Y.; Zhang, F.C. Effect of strain ratio on cyclic deformation behaviour of 7050-T6 aluminium alloy. *Int. J. Fatigue*, 129, (2019):105234.

29. Torres, M.A.S. and Voorwald, H.J.C., An evaluation of shot peening, residual stress and stress relaxation on the fatigue life of AISI 4340 steel. *International Journal of Fatigue*, *24*(8), (2002): 877-886.

30. Yin, F., Rakita, M., Hu, S. and Han, Q., Overview of ultrasonic shot peening. *Surface Engineering*, *33*(9), (2017): 651-666.

31. Badreddine, J., Rouhaud, E., Micoulaut, M. and Remy, S., 2014. Simulation of shot dynamics for ultrasonic shot peening: Effects of process parameters. *International Journal of Mechanical Sciences*, *82*, (2014): 179-190

32. Tekeli, S.Ü.L.E.Y.M.A.N., 2002. Enhancement of fatigue strength of SAE 9245 steel by shot peening. *Materials letters*, *57*(3), (2002): 604-608.

33. Li X, Zhang J, Yang B, Zhang J, Wu M, Lu L. Effect of micro-shot peening, conventional shot peening and their combination on fatigue property of EA4T axle steel. *Journal of Materials Processing Technology*. 1;275 (2020):116320.

34. Soyama, H., Chighizola, C.R. and Hill, M.R., 2021. Effect of compressive residual stress introduced by cavitation peening and shot peening on the improvement of fatigue strength of stainless steel. *Journal of Materials Processing Technology*, *288*, (2021): 116877.

35. Bagherifard, S. and Guagliano, M., 2012. Fatigue behavior of a low-alloy steel with nanostructured surface obtained by severe shot peening. *Engineering Fracture Mechanics*, *81*, (2012): 56-68.

36. Kumar, R.K., SampathKumaran, P., Seetharamu, S., Kumar, S.A., Pramod, T. and Naveen, G.J., Investigation of shot peening effect on titanium alloy affecting surface residual stress and roughness for aerospace applications. *Procedia Structural Integrity*, *14*, (2019): 134-141.