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Fatigue Behavior of AA5050 Alloy After Shot Peening Treatment

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Abstract

The pursuit of lighter materials has driven innovations across various industrial sectors, including aerospace, automotive, and naval, aiming for greater structural efficiency and improved mechanical performance. Aluminum alloys are widely studied for their fatigue behavior, especially in applications requiring both lightness and strength. Processes such as thermal and mechanical treatments, including shot peening, are employed to enhance the durability and performance of these materials under cyclic loading. This study investigates the fatigue behavior of the AA5050 alloy after shot peening treatment, using two types of shot media (AC 30 and AC 50). For this purpose, 20 specimens were manufactured using the wire electrical discharge machining (WEDM) process, followed by microstructural characterization through optical and scanning electron microscopy. Mechanical characterization included microhardness, residual stress, and fatigue tests, with the determination of the Wöhler curve.The results demonstrated that the shot peening treatment increased the fatigue resistance of the AA5050 alloy and improved its microhardness values.

Keywords
AA5050, Shot Peening, Fatigue, Residual Stress, Microhardness.

1. Introduction
The advancement of lightweight and high-performance materials plays a fundamental role in the development of modern technologies across several industrial sectors, notably in aerospace, automotive, and marine applications (Polmear, 2006; Davis, 1993). In these industries, the optimization of mechanical efficiency, structural integrity, and fuel economy strongly depends on the selection of materials that offer high strength-to-weight ratios, good corrosion resistance, and favorable fabrication characteristics. Aluminum alloys, particularly those belonging to the 5xxx series, such as AA5050, are widely recognized for meeting many of these requirements, owing to their non-heat-treatable strengthening mechanism, excellent formability, and natural corrosion resistance provided by the presence of magnesium as the primary alloying element (Kaufman, 2000).

Nevertheless, the behavior of these alloys under cyclic loading remains a challenge, especially for components subjected to repeated mechanical stresses throughout their service life. Fatigue failure is a primary mode of degradation in metallic materials, and its mitigation is a subject of intense research (Suresh, 1998). Among the strategies used to improve fatigue performance, surface mechanical treatments have proven to be particularly effective. One such technique is shot peening, which operates by plastically deforming the material's surface through the controlled impact of spherical media. This process introduces compressive residual stresses in the surface layer, which act to hinder the nucleation and propagation of fatigue cracks (Liu & Yao, 2008).

The effectiveness of shot peening is closely related to parameters such as shot size, intensity, coverage, and material properties of the media (Schulze, 2006). Variations in these parameters can lead to different levels of surface hardening and residual stress profiles, ultimately influencing the fatigue behavior of the treated alloy. Moreover, understanding the microstructural changes induced by shot peening, as well as their correlation with mechanical properties, is essential for the proper design and implementation of fatigue-resistant components.

In this context, the AA5050 aluminum alloy represents an attractive candidate for structural applications where cyclic loads are prevalent, and surface treatments like shot peening may offer significant performance enhancements. Characterizing and quantifying these effects through a combination of experimental fatigue testing, microstructural analysis, and mechanical evaluation is essential to assess the full potential of such treatments in real-world engineering applications.

1.1 Objectives
This study aims to evaluate the influence of shot peening on the fatigue performance of the AA5050 aluminum alloy. For this purpose, fatigue test specimens were produced using wire electrical discharge machining (WEDM) and then subjected to shot peening treatments using two different shot media, AC 30 and AC 50. The specimens were characterized microstructurally through optical microscopy and scanning electron microscopy to identify morphological changes in the surface and near-surface regions. Mechanical characterization was performed by measuring microhardness profiles and residual stress distributions. Fatigue testing was then conducted to generate Wöhler curves for each condition, enabling a comparative analysis between untreated and shot-peened specimens.

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The integration of microstructural and mechanical data seeks to elucidate the relationship between shot peening parameters and the resulting improvements in fatigue resistance of the AA5050 alloy.

2. Literature Review

Aluminum and its alloys are widely recognized for their favorable combination of low density, high specific strength, corrosion resistance, and formability, making them suitable for aerospace, automotive, naval, and structural applications (Polmear, 2006). Among the wrought non-heat-treatable aluminum alloys, the 5xxx series, alloyed primarily with magnesium, stands out for offering an excellent strength-to-weight ratio and good weldability (Kaufman, 2000). The AA5050 alloy, in particular, has found increasing industrial relevance due to its balanced mechanical properties and enhanced corrosion resistance in marine and industrial environments.

From a metallurgical perspective, AA5050 is classified as an Al-Mg alloy with moderate magnesium content, typically ranging between 1.1–1.8%. It exhibits a solid solution strengthening mechanism and does not undergo age hardening, which simplifies its processing but also limits certain performance enhancements (ASM International, 1990). The microstructure generally comprises equiaxed grains, and its properties are influenced by cold working and thermomechanical treatments.

Fatigue behavior is a critical performance parameter for components subjected to cyclic loading. In such conditions, premature failure can compromise structural integrity and lead to elevated maintenance costs and operational downtime. For Al-Mg alloys like AA5050, fatigue resistance is governed by surface condition, residual stress state, and microstructural features such as grain size, inclusion content, and dislocation density (Suresh, 1998).

Shot peening has emerged as a promising surface treatment technique aimed at improving fatigue performance by inducing compressive residual stresses at the surface and near-surface regions of metallic materials. This process involves bombarding the surface with spherical media (commonly steel or ceramic shots), causing localized plastic deformation and the development of a compressive stress field that retards crack initiation and propagation (Schulze, 2006; Liu & Yao, 2008). Numerous studies have demonstrated that shot peening can significantly enhance the fatigue life of aluminum alloys, particularly when optimized for parameters such as shot size, velocity, coverage, and material hardness (Bagherifard & Guagliano, 2019).

However, despite the proven efficacy of shot peening in alloys such as AA5083 and AA5052, there is a notable lack of comprehensive studies focused on the AA5050 alloy. Existing literature provides limited insight into the interplay between microstructural modifications, induced residual stresses, and fatigue life in this specific alloy when subjected to shot peening. Given its industrial potential and favorable properties, a deeper understanding of how different peening conditions affect the fatigue performance of AA5050 is essential. Such knowledge can support the development of more reliable components and contribute to sustainable engineering practices by extending service life and reducing material waste.

In this context, the present work seeks to contribute to the scientific and technological understanding of fatigue enhancement strategies for AA5050 through mechanical surface treatments, particularly shot peening. Emphasis is placed on characterizing residual stress profiles, microstructural evolution, and fatigue response resulting from different peening parameters, thereby addressing a gap in current materials engineering literature and practice.

3. Methods

In this study, samples of AA5050 aluminum alloy were subjected to shot peening to induce surface compressive residual stresses. The treatment was carried out using two types of shot: AC 30 (fine) and AC 50 (coarse), in order to evaluate the effect of particle size on the residual stress state at the surface.

Residual stress measurements were performed by X-ray diffraction (XRD) using Cr $K\alpha_1$ radiation at 40 kV, 20 mA, and a counting time of approximately 35 seconds per point. The 2θ range varied from 129.230° to 149.630°, with a step size of 0.1°. For the application of the $\sin^2\psi$ method, the following tilt angles were used: 0°, 18.4°, 26.6°, 33.2°, 39.2°, and 45° (Figure 1).
The analyses were conducted in two orthogonal directions: longitudinal and transverse (90°), as indicated in Figures 1a–c. The raw data were smoothed using the Savitzky-Golay method, applying a 15-point window to reduce noise while preserving the integrity of the diffraction peaks.

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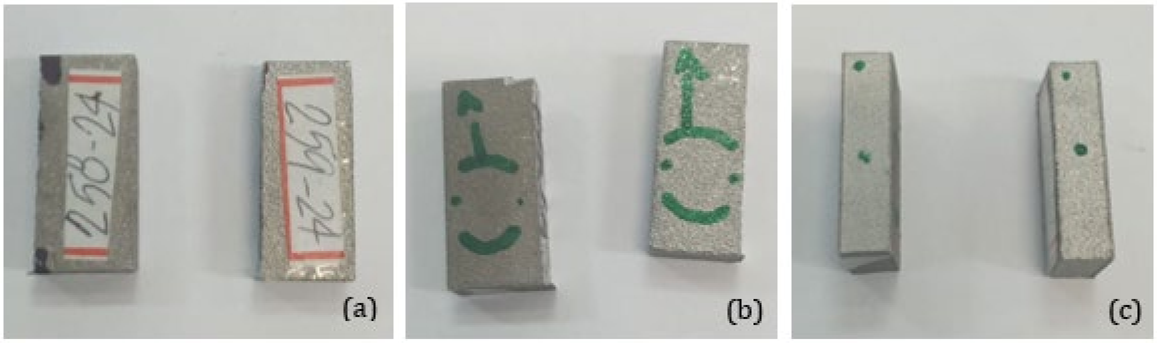


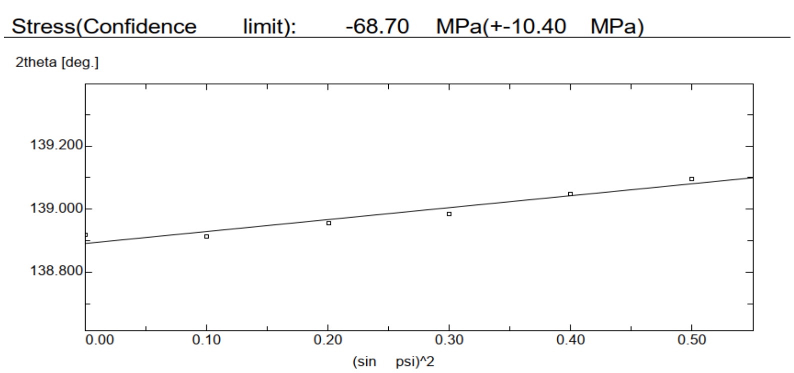
Figure 1. AA5050 samples (left: AC30 shot; right: AC50 shot), where: a – labeled samples; b – longitudinal direction marking; c – transverse (90°) direction marking.

The procedure followed the guidelines established by the NBR ISO 21432:2021 standard (ABNT, 2021), which defines the criteria for residual stress determination in metallic materials by XRD, based on diffraction peak shifts. Residual stresses were calculated by plotting the variation of the 2θ angle as a function of $(\sin \psi)^2$ and applying linear regression, using a stress constant of −180.89 MPa/°, Young's modulus of 71,900 MPa, and Poisson's ratio of 0.28 (CULLITY; STOCK, 2001).

3. Results and Discussion

The residual stress results revealed clear variations as a function of the analysis orientation, highlighting the anisotropic nature of the stress distribution induced by shot peening. In the longitudinal plane, specimen 258-24 exhibited a more pronounced compressive residual stress compared to the vertical plane, indicating that the peening process was more effective along the primary direction of surface exposure. Specifically, compressive stresses reached –68.70 ± 10.40 MPa longitudinally and –31.37 ± 5.57 MPa vertically. Conversely, specimen 259-24 displayed compressive residual stresses of comparable magnitudes in both directions: –66.10 ± 2.69 MPa (longitudinal) and –67.66 ± 2.53 MPa (vertical), suggesting a more uniform stress field throughout the surface.

Figures 2–5 illustrate the linear relationships between the diffraction angle 2θ and $(\sin \psi)^2$, from which residual stresses were determined via the $\sin^2\psi$ method, as prescribed by the NBR ISO 21432:2021 standard. The application of a stress constant of –180.89 MPa/°, Young's modulus of 71,900 MPa, and Poisson's ratio of 0.28 was consistent with established literature (Cullity & Stock, 2001), ensuring reliability and comparability of the measurements.



No.	Psi angle	(sin psi)^2	Peak Angle	Intensity	FWHM	Integ.Int.	Integ.w
1	0.0	0.000	138.918	3581	1.533	12774.39	3.568
2	18.4	0.100	138.913	3703	1.462	12028.63	3.248
3	26.6	0.200	138.956	3919	1.444	12065.31	3.079
4	33.2	0.300	138.985	3793	1.428	11492.70	3.030
5	39.2	0.399	139.048	2999	1.489	10086.49	3.363
6	45.0	0.500	139.097	2480	1.547	7938.70	3.201

Figure 2. Residual Stresses in the Longitudinal Plane (Specimen 258-24).

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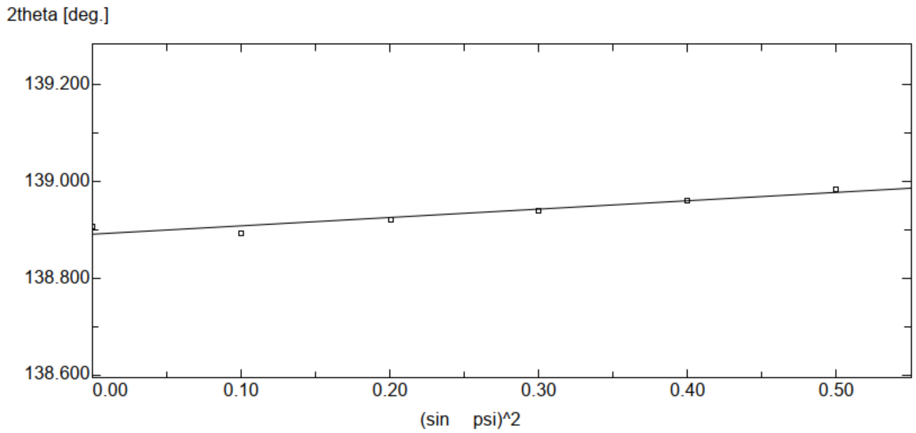
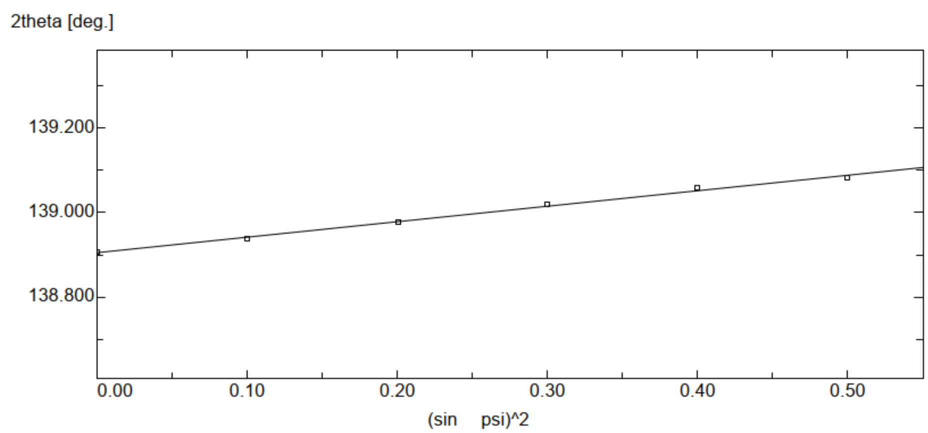
Stress(Confidence limit): -31.37 MPa(+-5.57 MPa)



No.	Psi angle	(sin psi)^2	Peak Angle	Intensity	FWHM	Integ.Int.	Integ.w
1	0.0	0.000	138.907	3364	1.548	12126.65	3.605
2	18.4	0.100	138.894	3431	1.481	11394.92	3.321
3	26.6	0.200	138.922	3266	1.472	10798.76	3.306
4	33.2	0.300	138.940	2968	1.476	10007.03	3.371
5	39.2	0.399	138.962	2666	1.518	9293.01	3.486
6	45.0	0.500	138.984	2454	1.548	7687.89	3.133

Figure 3. Residual Stresses in the Vertical Plane (Specimen 258-24).

Stress(Confidence limit): -66.10 MPa(+-2.69 MPa)



No.	Psi angle	(sin psi)^2	Peak Angle	Intensity	FWHM	Integ.Int.	Integ.w
1	0.0	0.000	138.907	3531	1.470	12479.70	3.534
2	18.4	0.100	138.937	3870	1.393	12120.01	3.131
3	26.6	0.200	138.977	3765	1.401	11704.54	3.109
4	33.2	0.300	139.018	3368	1.428	10843.12	3.219
5	39.2	0.399	139.058	2846	1.465	9747.58	3.425
6	45.0	0.500	139.082	2477	1.463	7784.62	3.143

Figure 4. Residual Stresses in the Longitudinal Plane (Specimen 259-24).

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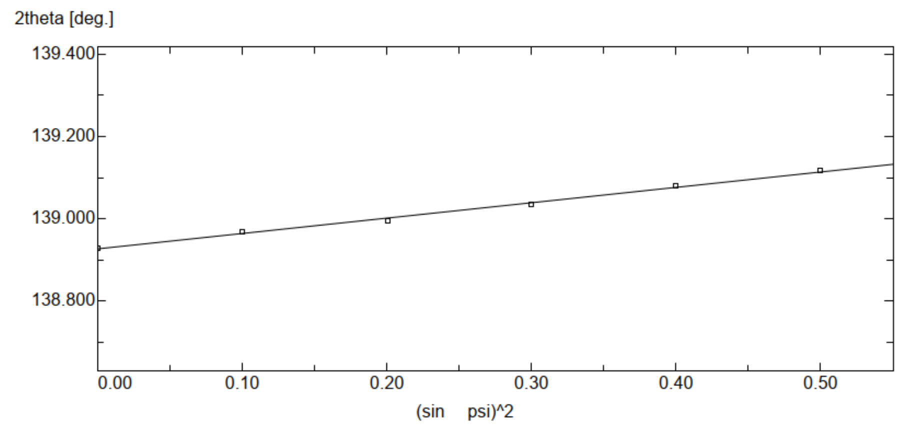
Stress(Confidence limit): -67.66 MPa(+-2.53 MPa)



No.	Psi angle	(sin psi)^2	Peak Angle	Intensity	FWHM	Integ.Int.	Integ.w
1	0.0	0.000	138.929	3087	1.457	10610.82	3.438
2	18.4	0.100	138.969	2589	1.462	9140.79	3.531
3	26.6	0.200	138.996	2742	1.426	9084.35	3.313
4	33.2	0.300	139.034	2840	1.405	8930.72	3.144
5	39.2	0.399	139.079	2354	1.439	7997.24	3.397
6	45.0	0.500	139.117	2126	1.446	6483.52	3.049

Figure 5. Residual Stresses in the Vertical Plane (Specimen 259-24).

The observed anisotropy in specimen 258-24 can be attributed to several factors. First, the finer shot size used (AC 30) may result in less uniform energy transfer during impact, leading to localized variations in plastic deformation depth and surface strain. This non-uniform distribution is supported by the higher standard deviation observed in both directions for this specimen. Additionally, the geometry of the sample and its orientation during the shot peening process may have influenced the effective coverage and angle of incidence of the shots, especially on vertical surfaces, where the impingement angle tends to be less direct.

In contrast, specimen 259-24, treated with the coarser AC 50 media, showed a more homogeneous compressive stress state. This outcome is in line with findings in the literature indicating that larger shot particles, due to their greater kinetic energy and contact area, tend to produce more uniform and deeper compressive layers (López et al., 2016; Sidhom et al., 2005). The smaller deviation in stress values between orientations further confirms the more consistent nature of the treatment with AC 50.

Interestingly, although it is generally expected that coarser shots generate higher magnitudes of compressive stress, specimen 258-24 (AC 30) presented a slightly more compressive value in the longitudinal direction than specimen 259-24. This apparent contradiction can be explained by the greater variability inherent in finer shot treatments, which can occasionally produce localized peaks of high compressive stress despite a lower average effectiveness. This observation aligns with previous studies showing that finer media can introduce sharper stress gradients and surface roughness variations that influence residual stress profiles (Peyre et al., 2000).

Moreover, the decrease in diffraction peak intensity with increasing ψ angles was consistently observed across all measurements, a behavior commonly attributed to the decrease in X-ray penetration depth at higher tilt angles, resulting in fewer diffracting atoms contributing to the signal (Cullity & Stock, 2001). Despite this, the linearity of the $(\sin \psi)^2$ plots remained high, reinforcing the validity of the regression-based residual stress determination.

Overall, the results suggest that the choice of shot size significantly affects not only the magnitude of induced residual stresses but also their directional uniformity and stability. These findings underscore the importance of carefully selecting peening parameters to optimize fatigue performance, especially in applications where stress orientation plays a critical role in crack initiation and propagation behavior.

4. Conclusion

The iso-inclination method using X-ray diffraction (XRD) proved to be an effective and robust technique for evaluating residual stresses in AA5050 aluminum alloy subjected to shot peening. The method accurately captured directional variations in the stress state, with higher compressive stresses observed in the longitudinal direction—particularly for specimen 258-24 indicating greater effectiveness of the treatment along that axis. This directional dependence may be attributed to factors such as shot impact angle and sample geometry during processing. The comparison between AC 30 and AC 50 media emphasized the influence of shot size on both the intensity and uniformity of residual stresses. The finer AC 30 media resulted in greater stress dispersion, suggesting less uniform impact distribution, whereas the coarser AC 50 shot produced more consistent compressive stress fields. This aligns with literature findings that associate larger media with more uniform surface deformation. The results also highlight the importance of consistent sample positioning and surface preparation to ensure reliable measurements using XRD, particularly when evaluating anisotropic stress distributions. In conclusion, the integration of residual stress analysis with controlled shot peening parameters offers valuable insight into the mechanical performance of AA5050, contributing to improved fatigue resistance and structural reliability in engineering applications.

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Biographies

Gabriela Marques Fernandes holds a degree in Control and Automation Engineering from the Federal Institute of São Paulo (IFSP – Guarulhos Campus) and is currently pursuing a Master’s degree in Materials Engineering at the IFSP – São Paulo Campus. She completed her secondary education in 2017 at Colégio Escola PSG and has since been building her academic trajectory with a focus on technologies applied to engineering, including automation, instrumentation, materials characterization, and industrial processes. She possesses intermediate proficiency in English and Spanish, with solid reading and comprehension skills in technical contexts. Gabriela stands out for her commitment to academic development and her continuous pursuit of technical and scientific improvement, with particular interest in applied research, materials innovation, and the integration of mechanical and electronic systems.

Rebecca Ribas de Oliveira Custodio is currently completing her degree in Control and Automation Engineering at the Federal Institute of São Paulo. This academic journey has provided her with solid theoretical and practical knowledge in engineering, preparing her for a career in the field. Her professional experience began in Manufacturing Engineering at Cummins Brazil, where she worked as an intern for 1 year and 2 months. During this period, she developed skills in processes, analysis, and problem-solving. She currently works as a Production Analyst at Cummins Brazil, having started on November 4, 2024. As a Production Analyst, Rebeca is responsible for evaluating production processes, ensuring efficiency, and identifying potential improvements for operational optimization.

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