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Influence of Shot Peening on Surface Integrity of Some Machined Aerospace Materials

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Editor: A. Niku-Lari.

ABSTRACT

Variations in machining parameters that are employed in traditional as well as nontraditional metal cutting operations can have a profound effect on surface characteristics such as microstructure, residual stresses and surface sensitive mechanical properties, specifically fatigue and stress corrosion resistance. This paper presents the effects of shot peening, a commonly employed postmachining operation, on the surface sensitive properties of several aerospace materials.

KEYWORDS
Shot peening; fatigue; stress corrosion; machining; surface integrity; aerospace materials

INTRODUCTION

Surface integrity is a subject that covers the description and control of the many possible alterations produced in the surface layers of materials during manufacturing, including the effects of these alterations on surface related physical and mechanical properties. Numerous investigations have been aimed at determining the sensitivity of surface-related material properties, such as fatigue and stress corrosion resistance, to the machining and finishing processes used in aerospace materials.

In any machining operation, surface alterations can be anticipated whether the metal removal process is a conventional one such as grinding or milling or a nontraditional operation such as electrical discharge machining (EDM) or electrochemical machining (ECM). Gatto and DiLullo (1971) determined that some of the most commonly encountered microscopic surface alterations are plastic deformation, laps and tears, microcracks, intergranular attack, and overtempered and untempered martensite (in the case of hardenable steels). These surface alterations are often the result of abusive machining practices and may be accompanied by surface tensile residual stresses.

Since, in nearly all fatigue loading or stress corrosion environments, failure of a component initiates at or very near the surface, machining alterations such as microcracks, tears, or intergranular attack can act as crack nucleating sites resulting in a significant depression of surface-related properties. However, if plastic deformation, accompanied by compressive residual stresses, is introduced on a machined surface containing such alterations, the resistance to crack growth afforded by the compressive layer enhances both fatigue and stress corrosion properties.

Shot peening is a mechanical operation which blends and cold works the metal surface as the result of an impacting stream of metal shot or glass beads. Plastic flow and lateral expansion of the surface caused by shot impact is resisted by the adjacent subsurface material and such action produces a residual compressive stress state in the surface. Koster et al. (1970, 1972, 1974) found that compressive residual stresses induced by shot peening can reach depths of up to 0.3 mm. The basic parameters of the peening process such as shot size and uniformity, exposure time, intensity, etc. need to be carefully controlled in order to achieve a uniform distribution of compressive stresses on the surface of a part. If the peening parameters are not properly controlled, then the beneficial effects of the peening operation may not be realized and, in some extreme situations, fatigue properties can even be lowered.

Subsequent discussions will deal with the influence of shot peening on the integrity of machined surfaces as related to surface sensitive properties such as fatigue strength and stress corrosion resistance.

SHOT PEENING AND ITS INFLUENCE ON FATIGUE LIFE

Over the past several years, many investigators including Koster et al. (1970, 1972, 1974) and Dickenson (1970) have demonstrated the effects of variations in metal removal parameters on the fatigue behavior of many alloys. Metallurgical studies and fatigue testing have revealed that, in many instances, degradation of fatigue strength can be traced to surface damage such as microcracks from an abusive grinding operation or intergranular attack (IGA) from a roughing ECM operation. In addition, Koster et al. also showed that the surface and near surface residual stress state created by the machining process significantly influenced fatigue strength.

In this paper, the high cycle fatigue data presented was the result of cantilever bending tests in fully reversed loading, under constant load amplitude at cyclic frequencies in the range of 1800-2000 cycles per minute. All tests were conducted at room temperature except as indicated. For all of the materials studied, specimens which were fatigue tested represented a wide range of machining practice from gentle to abusive. Fatigue curves were developed in order to demonstrate the endurance limit as a function of the particular machining operation. Subsequently, specimens machined under various conditions were shot peened and fatigue tested in order to ascertain the influence of this mechanical post processing operation.

Alloy Steel AISI 4340

The influence of shot peening was studied on grinding and electropolishing operations. The material was in the quenched and tempered condition exhibiting a tempered martensitic structure and a hardness of Rc50. Metallographic studies revealed that the shot peening operation did little to alter the surface microstructure apparently because of the relatively high hardness level of the material.

Fatigue testing revealed that shot peening was highly effective in elevating fatigue strengths. It is evident from the data in Figure 1 that shot peening a surface of high integrity and hence good fatigue properties, such as represented by the gentle ground condition, produced higher fatigue strengths than shot peening an abusively ground surface with poor surface integrity. (Fig. 1-6 are on page 36.) These findings indicate that the effect of prior damage from machining, which for hardened AISI 4340 may include surface microcracks, and layers of untempered and overtempered martensite accompanied by residual tensile stresses, is not entirely negated by the shot peening operation. Shot peening elevated the endurance limit of gently ground AISI 4340 from 703 to 772 MPa and the abusively ground material from 427 to 634 MPa. Note that only a modest increase in endurance limit was imparted to the electropolished sample by the shot peening operation. From a comparison of the changes in fatigue strengths introduced by peening, it can be seen that peening a surface with the greatest machining damage produced the most pronounced ameliorating effects.

Nickel Base Alloys

The influence of shot peening on fatigue life was studied on three nickel base superalloys which had been machined utilizing nontraditional metal removal methods: EDM, ECM and ELP. Metallographic study revealed that shot peening produced some modification of the surface microstructural features including blending of asperities and introduction of plastic deformation and resultant strain hardening.

Shot peening was found to be highly effective in elevating the fatigue strength of these alloys over that from the as machined condition. As evidenced from the data presented in Figure 2, the elevation in endurance limit produced by shot peening was nearly a factor of 2 in most instances and as great as a factor of about 3 in the case of EDM'd Inconel 718. This significant elevation in the fatigue properties of EDM'd Inconel 718 was attributed by Koster et al. to surface and subsurface compressive residual stress introduced by the peening process.

The beneficial effects of shot peening on fatigue life have also been shown to extend to elevated temperatures based on studies performed on nickel base alloy Rene' 95. The fatigue data in Figure 3 demonstrates the enhancement of fatigue properties at 810 K by shot peening surfaces machined by ECM and EDM.

Titanium Alloys

The influence of shot peening on fatigue performance was evaluated on mill annealed Ti-6A1-4V and solution treated and aged Ti-6A1-6V-2 Sn. Utilizing abusively milled Ti-6A1-4V as the baseline, shot peening was compared to other post-milling operations including polishing, vapor honing, abrasive tumbling, and chemical milling (CHM). The milling operation on Ti-6A1-4V created a continuous white layer and a slight loss in surface hardness due to overheating from this operation. Shot peening the surface produced a continuous plastically deformed layer which was accompanied by some strain hardening. Residual stress profiles determined by Koster et al. revealed that the greatest level of compressive stress was introduced by the shot peening operation while the other post processing operations and the baseline milling operation introduced compressive stress of considerably lower magnitude.

The fatigue data for Ti-6A1-4V in Figure 4 revealed identical elevations in fatigue strength from 358 (baseline) to 441 MPa for the shot peening, polishing and vapor honing operations. The fatigue strength of ECM'd Ti-6A1-6V-2 Sn was considerably elevated by the shot peening process. The most significant change was obtained by shot peening after an off-standard or aggressive ECM operation. In this case the fatigue strength was increased from 324 to 586 MPa. The fatigue data in Figure 5 show the influence of shot peening on this ECM'd alloy.

SHOT PEENING AND ITS INFLUENCE ON STRESS CORROSION RESISTANCE

Campbell (1971) showed that the compressive stresses introduced by shot peening retard stress corrosion cracking. The limited studies performed by Metcut Research also showed that shot peening was effective in increasing the stress corrosion life of AISI-4340 steel which had been subjected to grinding and ELP metal removal operations.

The stress corrosion evaluation procedure consisted of prestressing the specimens in bending to approximately 75% of the yield strength of the material and exposing them to a room temperature 3.5% sodium chloride aqueous solution meeting the requirements of Method 811 of Federal Test Method Standard 151. The specimens were immersed alternately in the salt solution and air on a continuous cycle of 10 minutes exposure to the solution and 50 minutes to the air. They were exposed in this manner until failure or a maximum of 1000 hours was achieved. Test results presented in Figure 6 show that shot peening after abusive grinding considerably increased the stress corrosion life. Shot peening after gentle grinding and after electro-polishing, however, gave only modest increases in stress corrosion life.

SUMMARY

The majority of the test results presented in this paper show that shot peening significantly elevated the room temperature high cycle fatigue properties of the materials studied. The shot peening of surfaces which initially exhibited good fatigue strength result in higher fatigue strength than shot peening of surfaces which initially exhibited poor fatigue strength as the result of surface damage or abusive machining practices. While the greatest improvements in fatigue properties were encountered from shot peening surfaces which were adversely affected by machining, the total effect of surface damage was not generally overcome. In addition to the fatigue effects reported for AISI 4340 steel, results indicated a beneficial influence on stress corrosion resistance from shot peening after grinding.

ACKNOWLEDGEMENT

This paper summarized work performed by Metcut Research Associates Inc. under USAF Contracts F33615-68-C-1003, F33615-68-C-1112, F33615-70-C-1589 and F33615-72-C-1385. The stress corrosion testing was performed by Boeing Company, Seattle.

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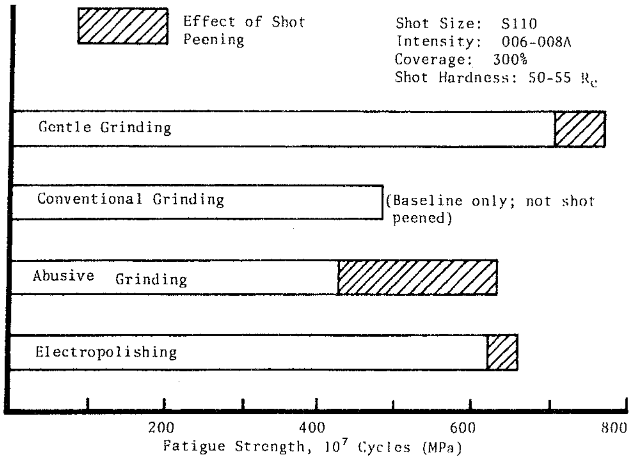

Fig. 1. Effect of shot peening on AISI 4340 Steel, Rc 50

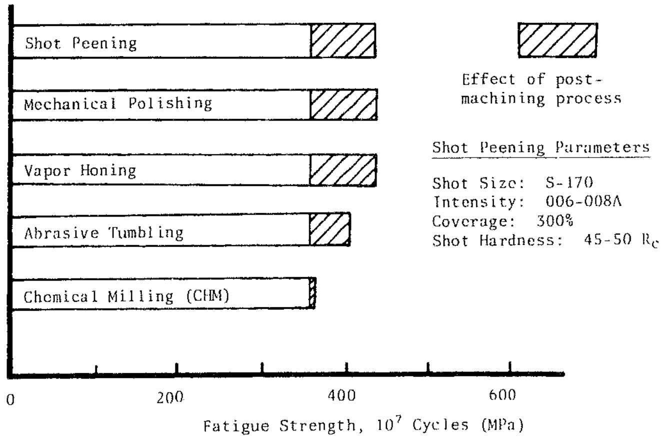

Fig. 4. Effect of several post-machining operations on the fatigue strength of abusively end milled Ti-6A1-4V (mill annealed)

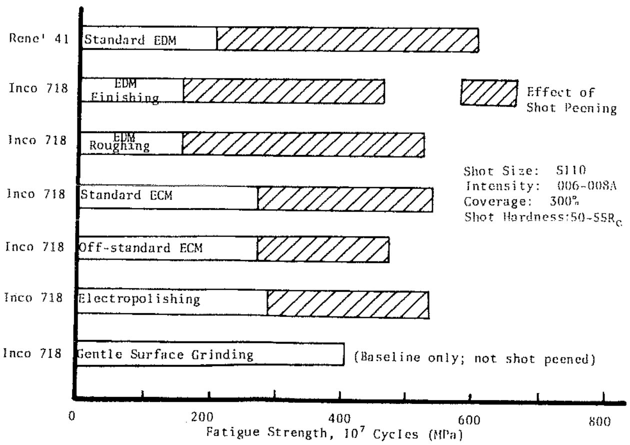

Fig. 2. Effect of shot peening on two Ni-base superalloys

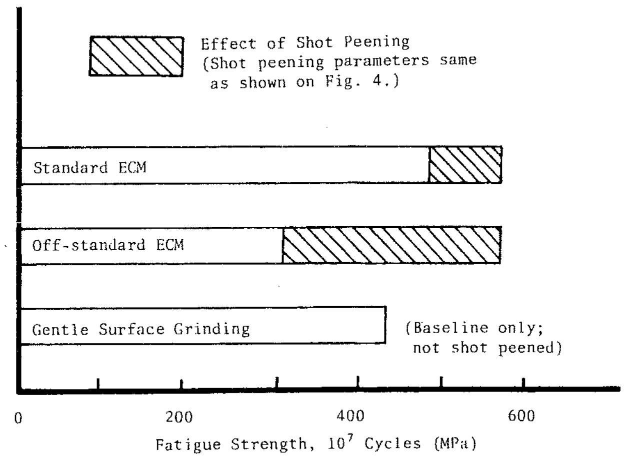

Fig. 5. Effect of shot peening after ECM on the fatigue strength of Ti-6A1-6V-2 Sn (solution treated and aged)

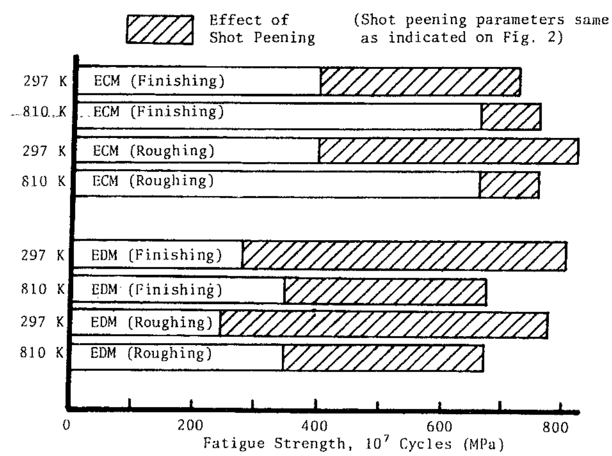

Fig. 3. Effect of shot peening after ECM and EDM on the fatigue strength of Rene' 95 (solution treated and aged) at 297 and 810 K

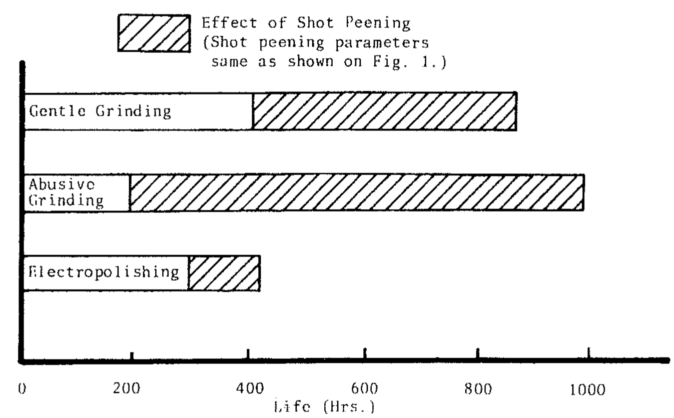

Fig. 6. Effect of shot peening on stress corrosion resistance of AISI 4340 Steel (Rc 50)