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X-RAY DIFFRACTION RESIDUAL STRESS MEASUREMENTS FOR QUALITY CONTROL TESTING

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ABSTRACT

This paper present the primary difficulties which are associated with the obtaining and interpreting surface X-ray diffraction residual stress results: the surface stresses may be identical for the shoot peening, nitriding and grinding parameters; many machining and grinding metal removal processes can generate local fluctuations in the surface residual stress; for many material removal and surface treatment processes the depth of penetration of the X-ray beam is quite shallow and can cause experimental error in the measurement of the surface stress. The stress distributions by conventional and abusive grinding of 4340 steel, the surface residual stresses for 5160 steel leaf springs shot peened may prohibit the use of non-destructive surface stress measurements.

KEYWORDS: XRD, Surface Residual Stress, Grinding, Machining and Shot Peening Processes

1. Introduction

X-ray diffraction (XRD) is a non-destructive and efficient analytical technique which reveals information about the crystallographic structure, chemical composition, and physical properties of materials and thin films. X-ray diffraction (XRD) methods of residual stress measurement have been widely used for forty years, particularly in automotive and aerospace applications, and interest in the use of XRD stress measurement for quality control testing is increasing. Specifications now exist requiring that minimum levels of compression be achieved by shot peening, and limiting the tensile stresses allowed on EDM'd and ground surfaces. Because of subsurface stress gradient appears difficulties in measuring and interpreting XRD surface residual stress results and limit the usefulness of surface data. The most common problems encountered in using XRD methods of residual stress measurement are related to the high precision required for measurement of the diffraction angles. XRD methods are applicable only to relatively fine-grained materials, and often cannot be applied to coarse-grained ***3*** castings. The shallow depth of penetration of the X-ray beam can be a disadvantage when trying to characterize a subsurface stress distribution with only surface measurements. This paper describes the assumptions, theory and limitations of XRD residual stress measurement as applied to the study of residual stress distributions produced by such processes as machining, grinding and shot peening. It exists three addressing the difficulties encountered in obtaining and interpretation of surface residual stress results: **I.** The surface residual stresses present on the samples are not representative of the processes which produced them; **II.** The stress (machining and grinding) practices produce variations in the plane of the sample surface; **III.** Material removal and surface treatment processes produce errors in measurement caused by the penetration of the X-ray beam.

2. Materials and methods

I. The shot peening and grinding processes produce surface residual stresses by variation of processing parameters. The stress distributions will be useful for quality control testing.

II. The metal removal processes which involving chip formations such as machining and grinding can generate pronounced local fluctuations in the surface residual stress. The deformed layer variation in the depth and magnitude and the heat input near the surface during chip formation can result in large differences in the resulting surface residual stresses. The apparent surface residual stress measured by X-ray diffraction will be dependent upon the size and the positioning of the irradiated area. If a small irradiated area is used, the assumption of uniform stress within the irradiated area may be satisfied, and the stress variation at the sample surface will be revealed. The surface stress variation can be so pronounced as to render non-destructive measurement useless for process control. The irradiated area may be made large enough to provide a useful average surface stress; but then the assumption of uniform stress in the irradiated area may be violated. The surface stress measured will be the arithmetic average within the diffracted volume, and will depend upon the details of technique used, such as the rotation angle Ψ and the diffraction angle 2θ, irradiated area.

III. For most materials of practical interest and the X-ray used for residual stress measurement, the effective depth of penetration of the X-ray beam is quite shallow. 50% of the diffracted radiation originates from a depth of less than 10 µm. The X-ray beam is attenuated exponentially as a function of depth. The rate of attenuation is governed by linear absorption coefficient which depends upon the composition and density of the specimen and the radiation used. Any "surface" measurement is an exponentially weighted average of the stress at the surface and in the layers immediately beneath it. In developing the relationship between the observed strain in the crystal lattice and the stress at the sample surface, the assumption was made that the residual stress is constant throughout the depth of penetration of the X-ray beam. Unfortunately, for many samples of practical interest, the stress varies rapidly with depth beneath the surface, and the assumption of constant stress is violated. The result can be errors as large as 600 MPa. The sign and magnitude of the potential error is dependent upon the subsurface stress gradient; i.e., the direction and rate of change of stress with depth into the sample surface. Because the depth of penetration of the X-ray beam also varies with the rotation angle Ψ and the diffraction angle 2θ, the apparent surface residual stress will depend upon the details of the technique chosen, specifically the radiation and angles selected, if a significant subsurface stress gradient exists.

3. Results

I. In the case of shot peening, where X-ray diffraction is usually applied, the surface residual stresses are independent of the peening parameters including shot size and Almen intensity. **Figure 1** shows the similar surface results of the stress distributions produced by shot peening Inconel 718 to 6-8 A and 5-7 C intensities.

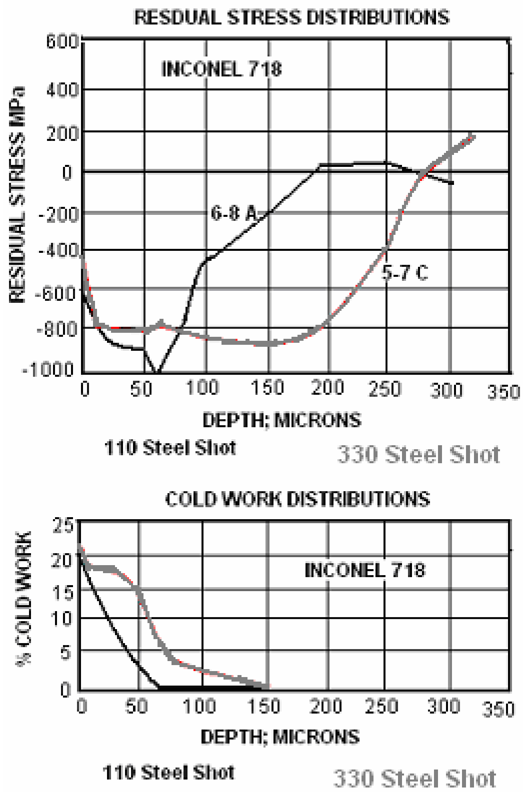

Fig. 1. *Variation of the Stress Distributions with the Depth Produced in Shot Peened Inconel 718*[5].

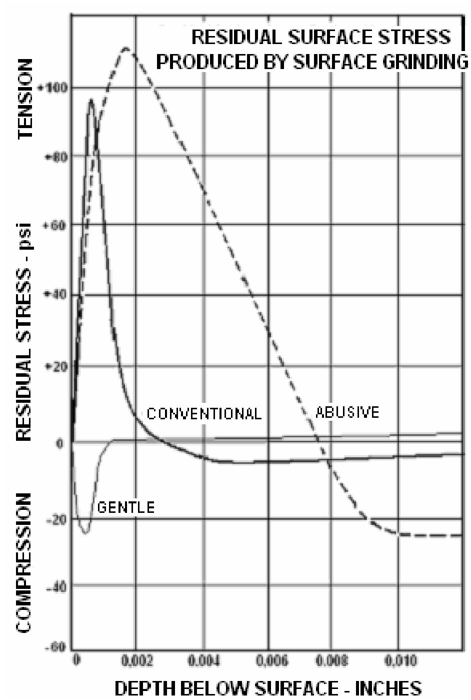

Fig. 2. *Surface Stress Distributions Produced by Gentle, Conventional and Abusive Grinding Conditions in 4340 Steel.*

The results indicate a pronounced variation in the depth of the compressive layers.

Grindings processes produce the surface stress independent of the grinding parameters. **Figure 2** shows the representations of 4340 steel of three kinds of grinding.

Grinding and shot peening produce comparable surface residual stresses in 8620 steel to an 18 A intensity (**Fig. 3**). It was observed that the non-destructive surface residual stress measurement cannot be used to distinguish the part which was in the ground or shot peened condition. That is why are used other cold abrasive processes such as grit blasting, wire brushing and polishing for to produce surface residual stresses indistinguishable.

A given level of surface residual stress is necessary to indicate that a critical component may have been correctly processed [1, 10].

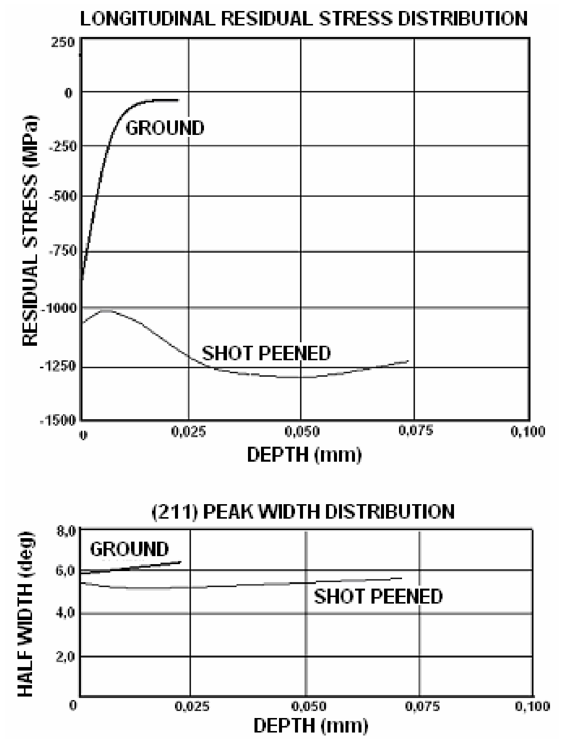

Fig. 3. *Residual Stress Distributions Produced by Shot Peening and Grinding of 8620 Steel.*

II. Figure 4 shows the surface residual stress measured using an irradiated area of 12mm x 0.5mm across a 19mm wide surface of a ground 4340 steel sample. The surface stresses vary by nearly 600 MPa from a region of maximum compression near one edge of the sample to maximum tension in a burned area. The use of a larger irradiated area, plotted as a horizontal line with a length equal to that of the irradiated area, yields the arithmetic mean, as expected.

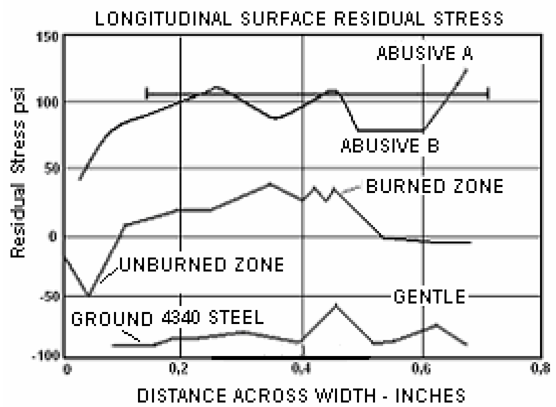

Fig.4. *Surface Residual Stress Variation in Surface of Ground 4340 Steel.*

Comparable variations in the surface residual stress are seen in **Fig. 5** for milled Inconel 718. Work hardening alloys often exhibit local areas of highly worked material at the sample surface.

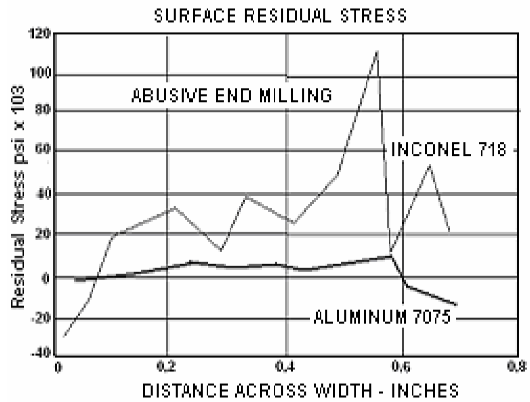

Fig. 5. *Surface Stress Variation in Milling of Inconel 718 and Aluminium [3].*

III. Figure 6 shows examples of large subsurface stress gradients produced by two different methods of nitriding 52100 steel. **Figure 1** shows a pronounced gradient in the "hook" commonly seen at the surface of shot peening stress distributions.

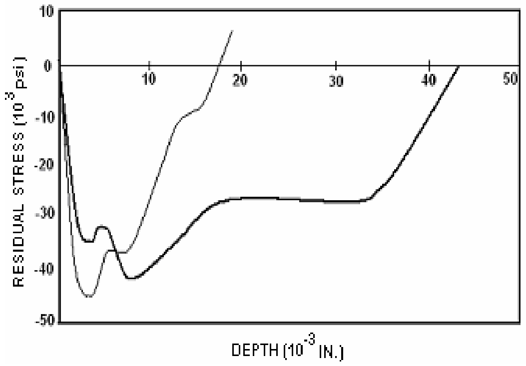

Fig. 6. *Subsurface Stress Distributions Produced by Nitriding 52100 Steel [4, 8].*

It is possible to correct for the errors caused by the penetration of the X-ray beam into the stress gradient, provided subsurface measurements are made by electro polishing to remove layers with sufficient depth resolution to accurately establish the stress gradient(9). Koistinen and Marburger (6) developed a method of calculating the true residual stress by unfolding the exponential weighting caused by penetration of the X-ray beam. Their often cited example of agreement between X-ray diffraction and mechanical methods of residual stress measurement in ground steel, reproduced in **Fig. 7**, shows agreement only because the correction was applied.

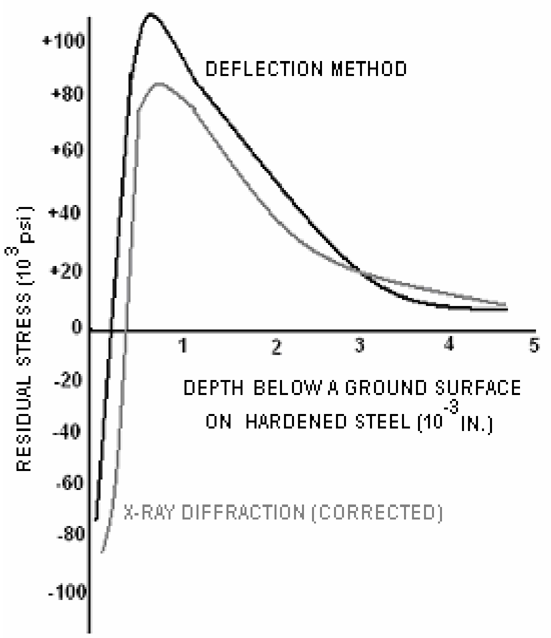

Fig. 7. *Subsurface Stress Distribution in Ground Steel Measured by Mechanical and X-ray Diffraction Methods with Correction (1).*

4. Conclusions

The limitations in the use of surface X-ray diffraction residual stress measurements have been shown to result in three areas of concern which must be considered before non-destructive surface results may be used reliably.

I. The surface residual stress measured non-destructively by X-ray diffraction is not correlated with the method of process control testing which produced the stress distribution. Subsurface stress differs significantly from the surface results.

II. Extreme local variation of the surface stress, frequently encountered on machined and ground samples, may prohibit the use of non-destructive surface X-ray diffraction residual stress measurement for quality control testing. The variability of the local surface stresses and the dependence of the results upon the measurement technique should be investigated before attempting to use surface measurements.

III. Non-destructive surface residual stress measurements cannot be corrected for errors caused by penetration of the X-ray beam into a varying stress field. The true surface stress frequently cannot be accurately determined by surface measurement alone.

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