

Hole Drilling With Orbiting Motion for Residual Stress Measurement – Effects of Tool and Hole Diameters

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ABSTRACT

Hole drilling is a very common technique for measuring residual stresses. Adding an orbiting motion of the drill was found to improve hole quality in difficult to drill materials and has been in practice for decades. This study compares measurements using various orbiting amounts. Each measurement was repeated twice to evaluate measurement statistics. There is a distinct, though relatively small, effect of the hole shape when no orbiting is used. It disappears already when the hole is 50% larger than the tool size. Different orbiting amounts also produce systematically different results. These may be related to the absolute hole size.

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BACKGROUND

The hole drilling method has been used for many decades, using strain gages to measure the change in surface shape around the hole as a result of the removal of residual stresses in the hole volume. Having to apply a strain gage for every measurement makes repeatability studies tedious, though. Optical methods have more recently been developed for measuring the surface change. ESPI (electronic speckle pattern interferometry) uses laser light and a digital camera to determine surface displacements as a fraction of the light wavelength. The only preparation required for a repeat measurement is the repositioning of the sample.

A similar investigation was reported on previously [1]. It used multiple tool sizes to measure stresses in the same sample, which was assumed to be homogeneous. The study compared the results of multiple orbiting offsets and found systematic differences as function of the ratio between the hole and tool diameters. While an effect of plunge drilling (ratio = 1) could be explained as being due to a hole shape difference, other differences were unclear. By adding a series of measurements with an additional tool size and multiple hole sizes, this study aims to clarify them. The same instrument was used for drilling experiments on the same sample, with the same type of drilling tools, the same drilling parameters and the same data analysis software.

The data analysis uses a single set of coefficients to describe the correlation between stresses and displacements. They were generated for a perfectly cylindrical hole. Without orbital motion, such a hole shape cannot be drilled even with the "square-end" end mills used. These tools leave an inverted cone on the bottom of the hole, which is significant for the stress results obtained for depths close to the cone height [1]. The inclination angle of their bottom cutting surfaces against the perfect cylinder bottom is approximately 3°.

EXPERIMENTAL

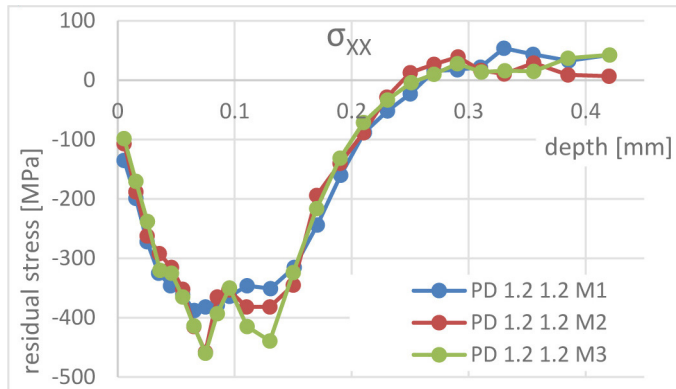
All measurements were performed with a Prism¹ residual stress measurement system [2]. It combines an electric drilling system with ESPI for measuring surface displacements. A green laser (532 nm wavelength) is used to illuminate the measurement surface and a digital camera to acquire images from before and after each drilling increment. The images are analyzed to generate displacements for each pixel. Stresses are obtained by fitting the displacement patterns with FEM derived coefficients that correlate stresses and displacements. The data analysis follows the Integral Method [3], equivalent to that for strain gage measurements as described in the ASTM standard [4].

The drilling tool is a commercially available, 2-fluted, TiN-coated, square-end end mill with a nominal diameter of 3/64" (~1.2 mm). The orbital motion was generated using a prototype attachment for the instrument. The orbiting speed varied as function of the hole size, approximately between 57 and 95 rpm. All other drilling parameters and the depth increments were kept the same and are the same as those used in the previous study. The rotation speed was 18,000 rpm. Holes with diameters of ~1.2 mm (plunge drilling PD), ~1.8 mm, ~2.4 mm (orbital drilling OD) and ~3.6 mm (ring drilling RD) were drilled, each three times.

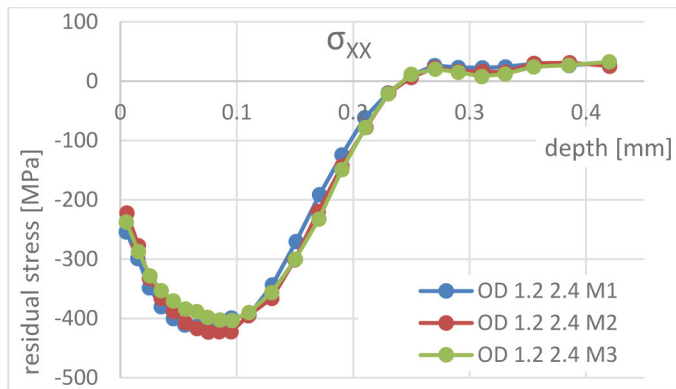
The sample chosen for the study is a flat, shot-peened aluminum plate of AA7075. It is expected that this sample has very similar stress depth profiles across the whole surface. The material is also easy to drill, which minimizes error sources related to the drilling process. The surface was lightly spray painted to improve the optical properties of the surface.

RESULTS

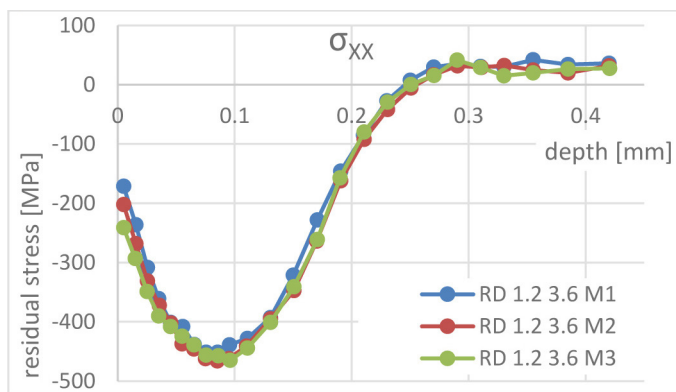
A selection of the individual stress depth profiles is shown in Figure 1 to demonstrate the level of repeatability. The clearly largest variability was found for the plunge drilling measurements (Fig. 1a). Repeatability was much better for all measurements with orbiting motion.



a.



b.

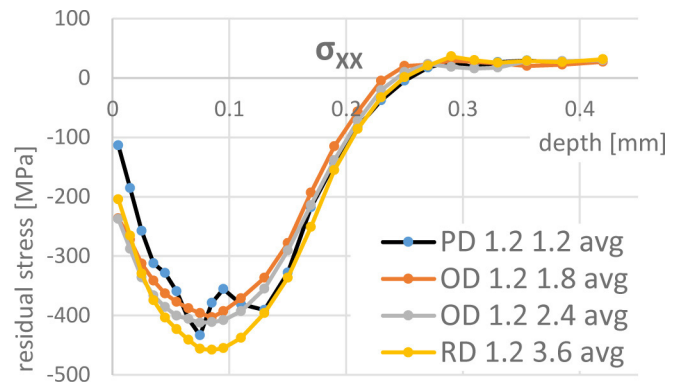


c.

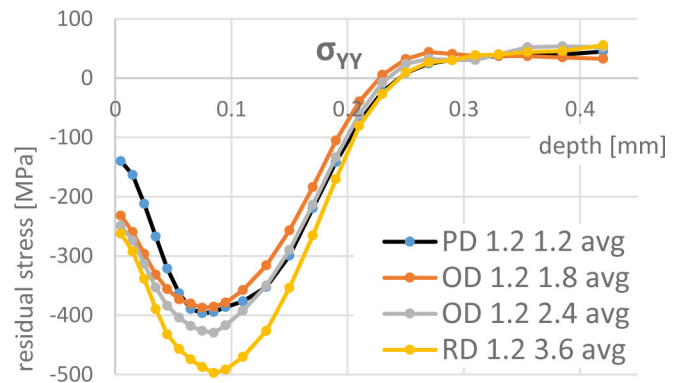
Figure 1. Repeatability of the measurements with a) a 1.2 mm hole (plunge drilling), b) a 2.4 mm hole (orbital drilling) and c) a 3.6 mm hole (ring drilling). The tool diameter was always ~ 1.2 mm.

The stress values for each nominal depth were averaged over the three measurements for each case. This allows comparing the results for the different orbiting amounts directly (Fig. 2). The plunge drilling stress profile clearly differs from the others at depths up to about 0.1 mm. All stress profiles obtained with orbiting motion start

with more compressive stresses and have similar shapes. Their starting and end points are very similar. However, the larger the hole and the larger the orbiting offset, the higher are the maximum compressive stresses. All these features are the same for stresses in horizontal (σ_{XX}) and the vertical (σ_{YY}) directions.



a.



b.

Figure 2. Average stresses from three measurements, each, comparing the results for different amounts of orbiting motion, in perpendicular directions.

DISCUSSION

The previous study showed a correlation between the deviation from a cylindrical hole shape after plunge drilling and smaller compressive stress results at small depths [1]. This is reproduced in the current results (Fig. 2). The difference between the volume actually removed and the cylinder volume assumed by the analysis model is greatest for the first depth increment and decreases from there. The estimated cone height for the tool used here is about 0.031 mm. But the effect proliferates because the stress depth profile is generated using a smoothing operation, Tikhonov regularization, as is recommended also for strain gage hole drilling [4]. Also, the material removal occurs parallel to the cone surface so that the actual depth range always extends to smaller depths than considered in the analysis.

The process used to determine the zero depth position of the drill adds variability, especially because the shot-peened sample surface is very rough. It differs for plunge drilling compared to orbital drilling in that it has to evaluate a very narrow ring of first contact rather than a larger area of approximately the same depth level. This is likely to