Estimation of Crystallite Size, Lattice strain and Micro Residual Stresses by FWHM method and impact of Feed rates on Residual stresses

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Abstract. The prediction and control of residual stresses of machined components is necessary. The tribological properties such as wear and tear are get influenced by it. The analytical assessment of residual stress profile of mechanically micro machined specimen with XRD (X Ray diffraction) technique are proposed. Also the lattice strain and crystallite sizes for different specimens were assessed. Residual stresses and feed rates are found significantly correlated and gets affected for Low Carbon Steel Specimens during micro milling.

Keywords: Micro-machining; Residual Stresses; Feed Rates; X-Ray diffraction.

1. Introduction

The material removal through WEDM (Wire Electrical discharge machining) involve erosion by electrical discharges ie. sparks occurring between metallic samples and electrode wire. The wire is separated from sample through a dielectric fluid and it is continuously feed to the zone of machining. It is a very important machining technique that is capable to machine almost everything which conducts electricity in spite of hardness from relatively common materials such as tool steel, aluminium, copper and graphite. During the machining with WEDM there is no significant physical pressure rise on the work piece when compared with the machining done by grinding wheels or milling cutters. It also leaves no residual burrs on the work piece along with complete or partial elimination of the need for consequence concluding operations.

The wire electrical discharge machining, material removal rate and surface integrity etc may be affected by various process parameters such as wire electrode (type, diameter and feed of wire), workpiece material (structure, conductivity, thickness), dielectric liquid (type, impurities, flow rate, temperature), discharge current, gap voltage, pulse duration and frequency, polarity, feed control mechanism.

Submerged WEDM enhances thermal stability along with effective flush although it generates a path of plasma between both the terminalsthat may turn thermal energy as high as 20000°Cdue to which melting of material takes place. When power supply is switched off, the path of plasma discontinued due to which a impulsively decline in temperature happens that allows the circulating dielectric fluid to beseech the plasma path and flush the molten particles from the pole surfaces in the form of microscopic debris. It also enables complex shapes and intricate geometries to be machined with extraordinarily high accuracy. Kunieda and Furudate tested the probability of conducting dry WEDM to advance the precision of the concluding operations. The experiment was conducted in the absence
of dielectric medium rather in a gas atmosphere. The deionised water is also used in WEDM as
dielectric fluid within the sparking zone as an alternative for hydrocarbon oil but it is not appropriate
for conventional EDM because it causes quick electrode wear even though its low viscosity and rapid
cooling rate make it ideal for WEDM. Optimum machining parameters for WEDM are selected with
significant amount of literature as inaccuracy may lead to short-circuit, wire breakage, surface damage
of work piece. With axial depth of cut and spindle speed the experiment has been designed to study the
residual stress generation during mechanical micro machining at different feed rates. Micro-
mechanical machining is a tool based fabrication technique for creating miniature devices and
components with features that range from tens of micrometers to a few millimeters in size. ”The
surface finish and integrity of manufactured components is also a very important aspect which in turn
gets affected by residual stresses. Hence it is important to estimate, predict and control residual
stresses.

2. Experimental Setup

2.1. Micro-Milling Setup
Half immersion end-milling operations were performed using micromachining tool MIKROTOOLS
DT-110 on the long edges of low carbon steel work pieces of size 50mm x 30mm x 10mm with a
500μm diameter end-mill at feed rates of 10mm/min and 15mm/min respectively. Following
operations performed to conduct experiment successfully are listed as below:

| Table 1. Micro Milling Experiment Details |
|------------------------------------------|
| Work piece | Low Carbon steel |
| Axial depth of cut | 300 micrometer |
| Feed rate (mm/min) | 20 30 |
| Spindle speed (rpm) | 1000 1500 |

2.2. Preparation of Secondary Sample
Followed by the preparation of Micro milled low carbon steel specimen, the specimen further cut into
small pieces for XRD testing. The following secondary samples were obtained as follows:
2.3. Preparation of Annealed Sample
Each one from the above said category of secondary specimens was annealed at 550°C to 650°C for one hour with air cooling. Remaining other sample from each category is treated as cold worked.

2.4. XRD (X Ray Diffraction) Testing
After preparing the specimens, XRD testing was performed on the annealed as well as cold worked samples separately from each samples in order to understand the effect of feed rates on residual stresses effectively. Copper radiations of wavelength 1.541836 Angstrom were used during XRD testing.

3. Results and Discussion
Measurement profiles were obtained for each case and the data with all the relevant information about the peak location after performing XRD testing. FWHM (Full width at Half Maxima), intensity of peak was obtained in tabulated form. This tabulated data was further used in analysis for the determination of lattice strain, crystallite size and residual stresses. The specification of work piece on which XRD has been performed is as follows:

### Table 3. Work piece specification

| Material       | Low Carbon Steel |
|----------------|------------------|
| Dimension      | 8mm x 8mm x 2 mm |
| Feed rate      | 20 mm/min        |
Table 4. FWHM data of annealed and cold worked specimen

| 2θ   | 1     | 2     | 3     |
|------|-------|-------|-------|
| 44.72| 57.74 | 82.77 |
| Sin θ| 380   | 482   | 661   |
| Bo   | 6.98×10⁻³ | 7.66×10⁻³ | 8.36×10⁻³ |
| Bi   | 5.38×10⁻³ | 5.48×10⁻³ | 5.45×10⁻³ |
| Bi²= Bo²- Bi² | 19.77×10⁻⁶ | 21.09×10⁻⁶ | 22.74×10⁻⁶ |
| BtCos θ| 4.11×10⁻³ | 4.68×10⁻³ | 4.75×10⁻³ |

Where,
- Θ: Location of peak (in degrees)
- Bo: FWHM (Full width at Half Maxima) for normal specimen
- Bi: FWHM (Full width at Half Maxima) for Annealed specimen

After performing the Broadening analysis, Crystallite size and Lattice strain were calculated using Scherrer formula, which gives the information that the crystallite size will be as small as the Peak width value increases,
Now the same procedure was followed and FWHM data was recorded for other sample 2, whose specifications are as follows:

Table 5. Work piece specifications

| Material       | Low Carbon Steel |
|----------------|------------------|
| Dimension      | 8mm×8mm×2 mm      |
| Feed rate      | 30 mm/min         |

**Figure 4.** Plot between BtCosθ×10^{-3} and Sinθ

**Figure 5.** Measurement Profile for Sample (Before Annealing) at Feed Rate 15mm/min
After performing XRD analysis and recording FWHM data for the second specimen and applying Scherrer formula following results were obtained.

![Figure 6. Plot between B,\(\cos\theta\times10^{-3}\) and \(\sin\theta\)](image)

Based on the above experimental work the obtained results can be tabulated here. Here micro residual stresses are increasing while increasing the feed rate with increment in lattices strain.

| Parameters               | Sample 1 (Feed rate 20 mm/min) | Sample 2 (Feed rate 30 mm/min) |
|--------------------------|--------------------------------|--------------------------------|
| Lattice strain           | \(2.24\times10^{-3}\)          | \(3.02\times10^{-3}\)          |
| Crystallite size         | 343 nm                         | 1762 nm                        |
| Micro Residual Stresses  | 395.60 Pa                      | 502.62 Pa                      |

3.1. Surface Roughness Measurement

Surface finish is also known as a surface texture. It comprises the small local deviations of a surface from the perfectly flat plane. There are a number of useful techniques for measuring surface roughness

i. Observation and touch method

ii. Stylus based equipment method

iii. Interferometry method

In this experiment we are using Stylus equipment method

3.2. Material Removal Rate Measurement

MRR can be defined as the volume of material removed divided by the machining time. 

\[ \text{MRR} = \text{Cutting speed} \times \text{Width of cut} \times \text{Height of workpiece}(\text{mm}^3/\text{min}) \]
3.3. Effects of process parameters on surface roughness

![Residual Plots for SR]

**Figure 7.** Process Parameters Graph for Surface Roughness

3.4. Graph of peak current for surface roughness

![Residual Plots for SR]

**Figure 8.** Graph of Peak Current For surface roughness
3.5. Process parameters graph for material removal rate

**Figure 9.** Process Parameters Graph For material removal rate

3.6. Graph of peak current for material removal rate

**Figure 10.** Graph of Peak Current For material removal rate
4. Conclusion
The FWHM method was successfully incorporated to estimate the Micro Residual Stresses, Lattice strain and Crystallite Size by the Broadening Analysis of the peaks. The crystallite size was determined using Scherrer Formula. Lattice strain was calculated by the slope of graph obtained with the help of FWHM Analysis. It was observed that the slope of the graph always remains positive; hence only Residual Stresses of tensile nature are produced while performing Micro-Milling operation and in particular are not desirable from the perspective of Strength, Components life and Wear resistance etc.

Increasing Feed rates were also having a substantial impact on the induced Residual stresses.

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