Machine Vision System for Correlating Wire Electrode Status and Machined Surface in WEDM of AlSi₃N₄ MMC’S

Gurupavan H R¹, H V Ravindra², Devegowda T M³, Rudreshi Addamani⁴

¹Research Scholar, Department of Mechanical Engineering, P.E.S. College of Engineering, Mandya, Karnataka-571401, India
²Professor, Department of Mechanical Engineering, P.E.S. College of Engineering, Mandya, Karnataka-571401, India
³,⁴Assistant Professor, Department of Mechanical Engineering, P.E.S. College of Engineering, Mandya, Karnataka-571401, India

Corresponding Author ¹Email: gpavan1989@gmail.com

Abstract. The technological developments in various sectors and requirement of complex shapes in manufacturing industries, the need for advanced materials has increased. Composite materials are one such advanced material. The most widely used composite materials is metal matrix composite. Conventional machining of these materials causes serious tool wear due to the presence of abrasive reinforcing particles and thus reduced tool life. Wire electrical discharge machining (WEDM) is quite successful for machining of metal matrix composites. Wire Electrical Discharge machining (WEDM) is a specialized thermal machining process capable of accurately machining parts of hard materials with complex shapes. One of the main research fields in WEDM is related to the improvement of the process productivity by avoiding wire breakage. Recently, vision systems are being exploited for such application mainly due to their high resolution, reliability and ease of automatic processing of data. Machine vision system is the technology used to provide image based automatic inspection and analysis for such applications as automatic inspection, process control and robot guidance in industries. This paper presents machine vision system, capable of providing wire electrode status and workpiece surface texture information in Wire electrical discharge machining of aluminium silicon nitride (AlSi₃N₄) composite material. The images of wire electrode and machined surface specimens were acquired using the machine vision system. From the analysis, a good correlation between the wire electrode and corresponding surface image was found. It is expected that these results would support further to establish a criteria for wire replacement in WEDM operation.

Keywords: Machine vision, WEDM, AlSi₃N₄, Surface finish, and Electrode Wear.

1. INTRODUCTION

Wire Electrical Discharge Machining (Wire-EDM) is a thermal machining process which is capable of accurately machining parts of hard materials with intricate shapes. Parts which are having sharp edges that pose difficulties to be machined by the main stream machining processes can be easily machined by Wire Electrical Discharge Machining process. However, selection of process parameters inorder to obtain higher cutting efficiency or accuracy in wire-EDM is not fully solved, even with the most up-to-date CNC wire-Electrical Discharge machine. This is mainly due to the complicated process mechanisms in WEDM. One of the main research fields in Wire-EDM is related...
to improve the process productivity by minimizing wire breakage. Different factors may lead to wire
breakage such as inefficient removal of erosion debris, decrease in flushing pressure as well as other
types of stochastic phenomena that appear during the machining process. In such case, the machining
process is stopped and the wire has to be threaded again, which leads to an undesired waste of time.
Therefore, it would be desirable to diagnose in advance low quality cutting regimes and consequently
predict wire breakage, in order to perform an on-line readjust of the machine parameter before it
happens.

Now a day, vision systems are being exploited for such application mainly due to their high
reliability, resolution and ease of automatic processing of data. Machine vision system is the latest
technology which is used to provide image-based automatic inspection & analysis for applications
such as process control, automatic inspection and robot guidance in the industries. First step in the
Machine Vision system is to capture the image, using cameras, lenses and lighting that have designed
to provide the variation required by subsequent processing. MV software packages contains various
image processing techniques to extract the required information and to make decisions such as pass or
fail, based on the extracted information.

In spite of the large amount of work worldwide on the application of machine vision for tool
status monitoring, such system have not been implemented on WEDM. Machine vision system can be
used to park and align the electrode precisely under the field of view of the camera for electrode status
measurement. By monitoring the electrode status, helps in avoiding unnecessary overhauls of
machines in good working orders, to detect the problem in time for planned replacements and repairs,
avoiding the breakdowns in production. The electrode is the only element in a wire-EDM that requires
frequent changes due to failure, either by wear or breakage. Hence, there is an imperative need to keep
a watch on the condition of the electrode during the machining process, so that the electrode can be
replaced in time.

Worn electrode state dramatically affects the texture of the machined surface. Analyzing the
texture of machined surfaces has been shown to be promising for electrode status monitoring.
However, most methods have their limitations when applied to real environments, where the
geometric features of machined surface depend on the machining operation and where image quality is
affected by illumination and other factors. Problems of non-uniform illumination and image noise can
be reduced by applying image segmentation and image enhancement techniques.

In the past, many researchers have investigated the effect of the WEDM process parameters on
surface roughness and electrode wear. Cabanes, et al., [1] investigates on avoiding wire breakage and
unstable situations in WEDM, as both phenomena reduce process performance and can cause low
quality components. The methodology followed in this work explains that in advance detection of
instability could be used to avoid the damaging effects associated with both wire breakage and
unstable machining. This methodology establishes the procedures to follow in order to understand the
causes of wire breakage and instability. In order to quantify the trend to instability of a given
machining situation, a set of indicators related to discharge energy, ignition delay time, and peak
current has been defined. Wire breakage risk associated to each situation is evaluated comparing the
evolution of those indicators with some previously defined threshold values. Srinagalakshmi Nammi
and Ramamoorthy, [2] have discussed on effect of surface lay in the surface roughness evaluation
using machine vision. This work explains the influence of orientation of surface lay of the machined
components, while analyzing the surface roughness using machine vision system. The machined
surface images were captured from milled low carbon steel specimens with different roughness values
using a vision system with coaxial lighting arrangement at various angular orientations of the
components. The captured images were subjected to pre-processing in order to retain the frequency of
components that attribute to roughness using a Gaussian filter by adapting the filtering procedures as
specified in ISO 4288. Various image based parameters are computed from the surface images
captured at different angular positions of the components. The vision parameters of surface roughness
are compared and correlated with the measured surface roughness (Ra) obtained using a stylus
instrument and the results are interpreted. The results clearly indicated that it is important to consider the orientation of the work piece when the machine vision approach is used to quantify the surface texture parameters.

Ossama B. Abouelatta [3] has discussed on a new approach to measure surface roughness in three dimensions by combining a light sectioning microscope and a computer vision system. This approach has the advantages of being non-contact, cheap and fast. Vision system is used to capture the images for successive profiles. Program has been developed using Matlab software to analyze the acquired images through four main modules: (Measurement controller, surface extraction or profile, 2D and 3D roughness parameters calculation).The system was used to measure different samples machined by various operations and the results were compared with a web-based surface metrology algorithm testing system and commercial software. The accuracy of the system was verified and proved to be within ±4.8% compared with these systems. Ghassan A., et al, [4] have discussed about a methodology for using machine vision data to acquire reliable surface roughness parameter measurement. Conventional stylus based measurements were compared with vision-based measurements using standard and non-standard surface roughness parameters. The two light reflection models namely Light Diffuse model and Intensity Topography Compatible model were adopted and applied to analyze the acquired vision data and to enable suitable computation of surface roughness parameters. Mu-Tian Yan, et al., [5] describes an electrode wear compensation method based on a machine vision system for micro-EDM. Front wear and corner wear of tool electrode can be measured and evaluated in a direct manner by the vision system’s image-processing software capabilities. Tool electrode images have depicted that the front wear and corner wear were increased rapidly during EDM drilling and EDM milling, respectively. A new electrode wear compensation method is presented based on the direct measurement of the front wear. Experimental results not only verify the usefulness of the electrode wear compensation method in micro-EDM, they also demonstrate that the machining time can be significantly reduced by 40% when using the proposed method, compared to the uniform wear method.

This paper discusses research work that analyzes images of work piece surface roughness and wire electrode in Wire EDM, and investigates the correlation between wire electrode status and quality characterizing machined surfaces. Results clearly indicate that wire electrode status monitoring can be successfully accomplished by analyzing surface image data.

2. EXPERIMENTAL WORK

Experiments were conducted on CONCORD DK7720C CNC Wire EDM. The basic parts of the Wire-EDM machine consist of a wire electrode, servo control system, a work table, dielectric supply system and a power supply. The CONCORD allows the operator to select input parameters according to the material and height of the component. The Wire EDM machine has several special features like, it uses the reusable wire technology. i.e., wire can’t be thrown out once used; instead it is reused adopting the re-looping wire technology. The experimental set-up for the data acquisition is illustrated in the Fig. 1. The Wire EDM process generally consists of several stages, a rough cut phase, a rough cut with finishing stage, and a finishing stage. But in this Wire EDM machine only one pass is used.
The gap between wire and work piece is 0.02 mm and is constantly maintained by a computer controlled positioning system. Molybdenum wire having diameter of 0.18 mm was used as an electrode. The control factors and fixed parameters selected are as listed in Table 1. The control factors were chosen based on review of literature and experts. Each time the experiment was performed, an optimized set of input parameters was chosen. In this study, four machining parameters were used as control factors and each parameter was designed to have Three levels denoted I, II, and III as shown in Table 1.

| Control Factors   | Level | Unit     |
|-------------------|-------|----------|
| Pulse-on time     | I     | 20 μ sec |
|                   | II    | 24 μ sec |
|                   | III   | 28 μ sec |
| Pulse-off time    | I     | 5 μ sec  |
|                   | II    | 6 μ sec  |
|                   | III   | 7 μ sec  |
| Current           | I     | 4 amp    |
|                   | II    | 5 amp    |
|                   | III   | 6 amp    |
| Bed speed         | I     | 30 μm/sec|
|                   | II    | 35 μm/sec|
|                   | III   | 40 μm/sec|
| Flush rate        |       | Constant |

Surfcom FLEX 50-A (Fig.4.10) is a compact, hand-held surface tester, there is no easier way of measuring, evaluating and documenting surface roughness. Surfcom flex measures not only horizontal and flat, but also vertical, overhead surfaces and simple measurement to waviness. In addition, 30 complete data records can be stored in the built-in memory and recalled at any time additionally USB memory can be used in Surfcom FLEX to save more data and Mini USB connector is embedded with Surfcom FLEX and able to connect with PC. The data can be sent to PC and various analysis is available with ACCTee software. It has the capability to measure roughness average (Ra), average maximum height of the profile (Rz) and maximum roughness depth (Rmax), etc., Table 4.10 gives the technical specification of Surfcom FLEX 50-A meter. It is easy to carry by compact design, it can be use anywhere, it has built in printer so we can take the print out directly just by inserting the print paper.

3. RESULTS AND DISCUSSION

Experiments were conducted on machining of Al-Si₃N₄ composite material. The machine used to conduct the experiment was CONCORD DK7720C CNC Wire EDM machine. The input parameters were pulse-on time, pulse-off time, bed speed and current. Response variables were wire electrode status and Surface roughness. Surface roughness and wire electrode status were measured using machine vision system, then it is compared with the surfcom flex 50-A and digital micrometer; which are conventional measuring instruments for measuring Surface roughness and wire electrode status respectively.
Machine Vision system implies the replacement of eye and brain in the human visual system by electronic cameras and digital computers respectively. Such systems are now being applied regularly in industrial automation for online inspection.

The operation of a machine vision system can be categorised in to the following functions:
- Image acquisition and digitization
- Image processing and analysis
- Interpretation

**Image acquisition and digitization**

Image acquisition and digitization function involve the input of vision data by means of a camera focused on the region of interest. Lighting techniques are frequently used to obtain an image of sufficient contrast for future processing. The elements of the matrix are called picture elements or pixels, in which each element has a value that is proportional to the light intensity of that portion of the scene. A single pixel is the projection of a small portion of a scene, which reduces that portion to a single value. The value is a measure of the light intensity for that element of the region, each pixel intensity is transformed into a digital value.

**Image enhancement**

Adjust the brightness and contrast of an image. Use window levelling on an image. Use geometrical transformations on an image. Use filters to improve image quality and extract objects. Histogram equalization operations change the intensity distribution of an image. It is possible to perform uniform histogram equalization with MATLAB. The uniform histogram equalization results in a uniform distribution of images pixel values.

**Image processing and analysis**

The amount of data that must be processed and analyzed is important. Several techniques have been developed for analyzing the image data in a machine vision system.

The images acquired by the machine vision system is shown in fig.3.1.

![Machine vision system for monitoring Electrode status](image-url)
3.1 Wire Electrode status visualization and monitoring

Fig. 4: Image of the Wire electrode before machining

Fig. 5: Image of the Wire electrode after machining

Fig. 6: Binary image & Region of interest selection before machining

Fig. 7: Binary image & Region of interest selection after machining

Fig. 8: Feature extracted of Wire electrode before machining

Fig. 9: Feature extracted of wire electrode after machining
An image of the wire electrode was captured using Nikon D-90 high resolution digital camera. Program written in Matlab software using image processing toolbox was used for analysis of the captured image using. Electrode wear vision parameter was computed from the stored image using this program.

This parameter was then compared with the Electrode wear measured using digital micrometer to identify whether the optical parameters are sufficient in themselves to characterize an electrode wear.

3.2 Surface Roughness Measurement

In the present work, the method for measuring surface roughness (Ra) is based on the analysis of the distribution of light intensity from a rough surface. Experiments were carried out to investigate the feasibility of vision based parameters for the measurement of surface roughness generated by machining processes. Initially, experiments were performed on CNC Wire EDM for getting different roughness values using DoE technique. The stylus parameters average surface roughness (R\textsubscript{a}) of these specimens were measured using stylus-instrument.

In conducting the machine vision experiments, a good florescent light source was used to illuminate the rough surface of the workpiece.

An image of the reflected light was captured using Nikon D-90 high resolution digital camera. A program written in Matlab software using image processing toolbox was used for the analysis of the captured image. Average surface roughness vision parameter was computed from the stored image using this program. Vision parameter was then compared with the average surface roughness (R\textsubscript{a}) to identify whether the optical parameters are sufficient in themselves to characterize a surface of the workpiece.

Regional maximum approach method is based on the relative gray level intensity of the each pixel with its surrounding pixels. It was assumed that the peaks on any surface will reflect more light than its surroundings and the parameter is calculated based on the distribution of these peaks. The gray image is converted into binary image by assigning “1s” for pixel having more intensity values than its surrounding pixels in the cell and remaining all into “0s”.

**Vision-Based Parameter Computed**

The arithmetic average of the gray level intensity matrix was computed using

\[
G_a = \frac{1}{N} \sum_{i=0}^{255} (F_i X_i)
\]

Where \(F_i\) is the number of pixels at grey-level \(X_i\), and \(X_i\) are the grey levels (\(i = 0, 1, 2 \ldots , 255\)), \(N\) is the total number of pixels in the distribution.

**Fig. 10:** Machined surface image  
**Fig.11:** Histogram equilized image
3.3 Correlating tool status and surface roughness

![Graph showing correlation between electrode wear and surface roughness](image.png)

**Fig. 12**: Surface Roughness (Ga) and Electrode Wear (Pixels), as a function of Machining time

This section explains how the surface roughness parameter is employed for correlating with different wire electrode status using machine vision system. Wire electrode wear causes a change in surface roughness as machining time elapses.

The above graph shows that there is an increased magnitude of the surface roughness as a result of increased wire electrode wear.

4. Conclusion

In this paper, a machine vision system has been implemented on Wire EDM machine to measure wire electrode status and surface finish of the workpiece. With the aid of image-processing software, this developed vision system has been well constructed to precisely measure the wire electrode status and surface finish of the workpiece. For real time surface texture condition monitoring with non contact techniques, the image processing algorithms can be used for enhancing the automation proficiency in unmanned tool.

The results obtained in each case shows that the procedure explained in this work is able to correlates surface roughness and wire electrode status by monitoring machine vision images.

The present work clearly indicates that the Machine vision approach can be used to measure the surface roughness and wire wear in WEDM. Results clearly indicate that wire electrode status monitoring in WEDM can be successfully accomplished by analyzing the surface image data.

References

1. I. Cabanes, E. Portillo, M. Marcos and J.A. Sańchez, “An industrial application for on-line detection of instability and wire breakage in wire EDM”, journal of materials processing technology 195 (2008) 101–109.
2. Srinagalarakshi Nammi and B. Ramamoorthy, “Effect of surface lay in the surface roughness evaluation using machine vision” Optik 125 (2014) 3954–3960.
3. Ossama B. Abouelatta, “3D Surface Roughness Measurement Using a Light Sectioning Vision System”, Proceedings of the World Congress on Engineering 2010 Vol I WCE 2010, June 30 - July 2, 2010, London, U.K.
4. Ghassan A. Al-Kindia and Bijan Shirinzadeh, “An evaluation of surface roughness parameters measurement using vision-based data”, International Journal of Machine Tools & Manufacture 47 (2007) 697–708.

5. Mu-Tian Yan, Chin-Yen Lo and Kuo-Yi Huang, “A study on electrode wear sensing and compensation in Micro-EDM using machine vision system,” International Journal of Advance Manufacturing Technology (2009) 42:1065–1073.

6. Nihat Tosun and Can Cogun, “An investigation on wire wear in WEDM”, Journal of materials processing technology, 137 (2003) 273–278.

7. A. Okada, Y. Uno, M. Nakazawa, and T. Yamauchi, “Evaluations of spark distribution and wire vibration in wire EDM by high-speed observation” CIRP Annals - Manufacturing Technology 59 (2010) 231–234.

8. Adrian Iosub, Gheorghe Nagit and Florin Negoeescu, “Tool Wear Investigation In Electric Discharge Machining Of Aluminum Matrix Composite Materials”, The Annals Of “Dunărea De Jos” University Of Galați Fascicle V, Technologies In Machine Building, Issn 1221- 4566, 2009.

9. I. Cabanes, E. Portillo, M. Marcos, and J.A. Sa’ nchez, “On-line prevention of wire breakage in wire electro-discharge machining”, Robotics and Computer-Integrated Manufacturing 24 (2008) 287–298.

10. Gurcan Sanzas, “Measurement and evaluation of surface roughness based on optic system using image processing and artificial neural network”, International Journal of Advanced Manufacturing Technology (2014) 73:353–364.