EFFECT OF TOOL WEAR ON TURNED SURFACE USING CONTINOUS WAVELET TRANSFORM

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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Abstract

This paper deals with the experimental study of the effect of tool wear on the surface machined profile uing continuous wavelet transform during turning operation of stainless steel workpiece using coated carbide tool inserts gred GC2025. By using a proper wavelet family to represent the profile of the turned surface, evaluation on which wavelet family is suitable to study the effect of tool wear on the turned surface's profile is also done in this paper. Coefficients values such as mean, root-mean square and variance are extracted from the wavelet profile of the surface to observe the relationship of these coefficients values to the effect of the tool wear on the turned surface.

Keywords: feed rate(fd), Mexican hat(Mexh),Wavelet Transform(WT), Symlet 30(sym30), Daubichies 40(DB 40), Morlet(Morl), Continuous Wavelet Transform (CWT)

1.0 Introduction

Precise machining such as turning is highly demanded by most of the manufactures around the globe. In turning machining, tools are fed to the surface of the workpiece subjected with friction, high pressure and heat which lead tool to wear. Hence, tool wear is the most common defect that we can notice on the appearance of the tool. Types of tool wear are;

I. Flank wear
II. Nose wear
III. Crater wear

Above are the types of tool wear on tool surface that will occur after some duration of machining operation. Any surface change on the cutting tool is not obviously noticeable. One of the big challenges in machining is replacing the cutting tool at the right time [13]. Machining with a worn tool will affect the smooth surface of the machining workpiece. The purpose of this study is to investigate of the effect of tool wear on the turned surface by using continuous wavelet transform(CWT) with proper mother wavelet along with the decomposition level to perform an accurate CWT of turned surface images. This project is based on the machine vision. In this study, surface profile of the turned workpiece captured using a CCD camera. Then, this image will be processed using MATLAB software and analysed the image with the aid of continuous wavelet transform.

Figure 1: Showing a good turned surface

Figure 2: Showing a poor surface turned

Figure 1 is an example of a surface profile that produced by an unworn tool. The smooth waviness of the profile indicates the cutting tool is in good condition. While, figure 2 shows the irregular surface profile which relate the damaged cutting tool. Tool condition can be observed by viewing the surface profile also there are some machining parameters that can be extracted from the profile. Surface texture is a macroscopic region of machined surface where primitives are situated repeatedly, contains the information about the machining conditions such feed rate, depth of cut, machining speed, alignment of work piece and interaction between cutting tool and work piece. Machined surface image is also carrying the information about condition of cutting tool by tool imprint on workpiece[17].Light rays reflected from the machined surface to the camera lens, gives information about the changes of surface texture with machining time and machining conditions. The surface finish would be imperfect as the cutting tool worn. [15]

Continuous Wavelet Transform is used to analyse the surface image, involves representing time varying function or signal in terms of simple, fixed building blocks termed wavelets. Wavelet has an ability to decompose a signal into an effective scale-time space representation allowing localization of events in time. Wavelet transform is a mathematical transformation which represents a signal. It is generally a mathematical function that multiplies the signal during all its length, with elongated and compressed versions of a mother wavelet that satisfies,

$$\psi_{d,t}(x) = \frac{1}{\sqrt{d}}\psi\left(\frac{x-t}{d}\right) \quad (1)$$

Two types of wavelet transform, continuous wavelet transform (CWT) and discrete wavelet transform (DWT) are there. CWT of a function expressed as:

$$\mathrm{CWT}f_{d,t}(x) = \langle f, \psi_{d,t}\rangle \quad (2)$$

In a complete form, the mathematical equation of the CWT is:

$$\langle f, \psi_{d,t}\rangle = \frac{1}{\sqrt{d}}\int_{-\infty}^{+\infty} f(x)\psi^*\left(\frac{x-t}{d}\right)dx \quad (3)$$

where the parameter *d* is a scaling factor which stretches, or compresses the mother wavelet. Parameter *t* is translation along the time axis and simply shifts a wavelet and delays or advances the time at which it is activated. The stretched and compressed wavelets through translation and scaling operation are used to capture the different frequency components of the function that being analysed [14]. The translation operation involves shifting of the mother wavelet along the time axis to capture the time information of the function to be analysed at different position. Wavelet transform is capable compressing or denoising a signal without appreciable degradation and provides good resolution in both time plus frequency domains synchronously where information in time domain at different frequency bands can be extracted. Wavelet transform represents the original surface in terms of wavelet coefficients. With the coefficients and based on what is known about the surface, it is possible to separate multiple scale features of the surface and filter noise. Wavelets analysis has proven to be more powerful than traditional filtering techniques such as Fourier analysis. Application of wavelet transformations in processing and analysis of the data acquired from the machine tool, allows efficient analysis of various dynamic and stationary signals from mechanical systems which proves its efficiency in feature extraction. It has been shown that time-frequency methods are very good for the extraction of features[7] .

In the work carried out by Kassim et al. [15], a fractal model applied on machined surface images to determine the fractal dimension and used hidden Markov method to classify four stages of tool wears based on fractal dimension. A second order statistical texture analysis technique called grey level co-occurrence technique has been applied on turned surface images by Datta et al.[12] for progressive tool wear detection. However, any study about the variation of texture features with different machining conditions has not been presented in their research. Velayudham et al.[6] used the wavelet transform as a tool to study the signal characteristics of cutting processes. But in his studies, lack of detailed investigation of the selection of wavelet basis functions and decomposition levels.

Morala-Argüello et al.[7] applied one level wavelet decomposition using Haar wavelet to the turned surface image. They classified the surfaces into two types with maximum 2.91% error using back propagation neural network (BPNN). They have also selected vertical details for analysing turned surfaces. They extracted the mean of vertical details of decomposed image as a surface feature, but Haar wavelet is a discontinuous function which is undesirable in the decomposition to the turned surface. Josso et al.[16] applied a frequency normalized DWT to get a ready space-frequency map of a surface image. They applied this technique on cast, ground and milled surface images using daubechies wavelet of order 20 as mother wavelet base. Wang et al.[8] extracted dynamic characteristics of tool wear from daubechies wavelet coefficients and normalized the extracted features by analysing vibration signals. Signal energies at various scales were used as a feature set for a Hidden Markov Model (HMM) that evaluated the likelihood that the observed signals came from either a worn or a sharp tool. The tool was assigned to the worn or sharp tool class based on which situation had a higher likelihood, related to the HMM. It is reported that HMMs make efficient use of the training data as compared with “traditional classifiers” and thus can perform well with limited amount of training data.

However, there is no literature available on selection of proper wavelet basis for analysing 2-dimensional surface profiles (machined surface images). Also, there is no study on the correlation of extracted features after applying CWT on machined surface images with VB average, which is inevitable for progressive monitoring. Wavelet analysis has found important applications in signal analysis and processing in various science and engineering fields. It has also been successfully applied to Tool Condition Monitoring (TCM) systems [9].

2.0 Experiment setup

In this work, a methodology has been carried to analyse the texture of machined surface images resulting from turning operations with the help of wavelet analysis method.

2.1 Work material

A lathe machine was employed to perform high-speed finish turning experiments on stainless steel. Before cutting, the work material was made into a solid cylindrical bar with a diameter of 40 mm. Cutting tool used was coated carbide turning tool with gred GC2025. The nose radius of tool N=0.4mm. GC2025 in combination gives excellent performance, with a soft cutting action in stainless steel and in toughness demanding operations in steel. Suitable for mixed production as the insert geometry works well in different workpiece materials.

The tool then scanned for the wear inspection using Hitachi Tabletop Microscope Tm-1000. It is the perfect "cross-over" imaging platform that bridges the gap between light microscopy and conventional SEM. Surface morphology is shown in stereoscopic detail with image contrast resulting from variances in the atomic number composition of the sample. TM-1000 provides a real alternative to optical microscopes, stereo microscopes, and confocal laser scanning microscopes. With the integrated “Charge-up reduction mode”, even samples that are prone to charging can be observed at high magnification with little or no disturbances.

2.2 Cutting condition

Two cutting condition were used during this research study. The feed rate was almost at the same magnitude as the tool edge radius of the round-edge tools to magnify the tool edge effect. The depth of cut was 3 times higher than the tool nose radius. No coolants were employed in the cutting experiments to increase the rate of tool wear. Two experiments were done in this research study. Ten passes were done for each experiment with following cutting parameters.

EXPERIMENT 1	EXPERIMENT 2
spindle speed= 185 mm/min	spindle speed= 185 mm/min
feed rate= 0.2mm/rev	**feed rate= 0.3mm/rev**
depth of cut = 1.2mm	depth of cut = 1.2mm

Table 1: Showing machining parameters for 2 experiments

2.3 Measurement and processing

In image processing, the image of turned surface captured offline using CCD camera. After machining, the image of turned surface will be captured few times. The imaging of the turned surface was aided by back lighting. The direction of the lighting is crucial. Lighting is a medium that reflects the information of the turned surface to the CCD camera. Improper direction of lighting may result in blur or unfavourable images [11]. After captured images of turned surface, the image is cropped through MATLAB image cropping command.

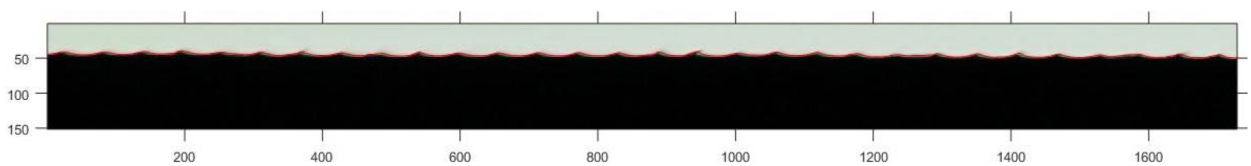


Figure 3: Cropped image of surface profile using MATLAB

Figure 3 is the example of cropped image of a profile from above experiments. The original profile was dimension with 5184 pixels in length. The image is cropped with 1/3 of the original profile length. Decomposition was done using MATLAB software for making the images fine to analysed with wavelet transform. In the case of a smooth surface produced by a sharp tool, regular reflection of incident light from the machined surface giving a uniform appearance of feed marks. Thus, the texture analysis of the machined surface image can quantify the condition of the cutting tool (A. Dattaa, 2013). Image then analysed via MATLAB software using CWT. Wavelet Transform (WT) of a signal is a function of two parameters, namely time and scale, the latter being the key point of the WT (Sukhomay Pal *et al.,*2009). WT works with a scaled window which allows the visibility of the entire frequency content. With WT, the pattern of the turned surface of the fine tool and worn tool can be observed clearly. Figure 4 shows the experimental setup for this research study. This setup was used to capture the image of the surface profile using the back lighting, below the workpiece. A filter paper was used to focus the light rays on the surface of the stainless steel.

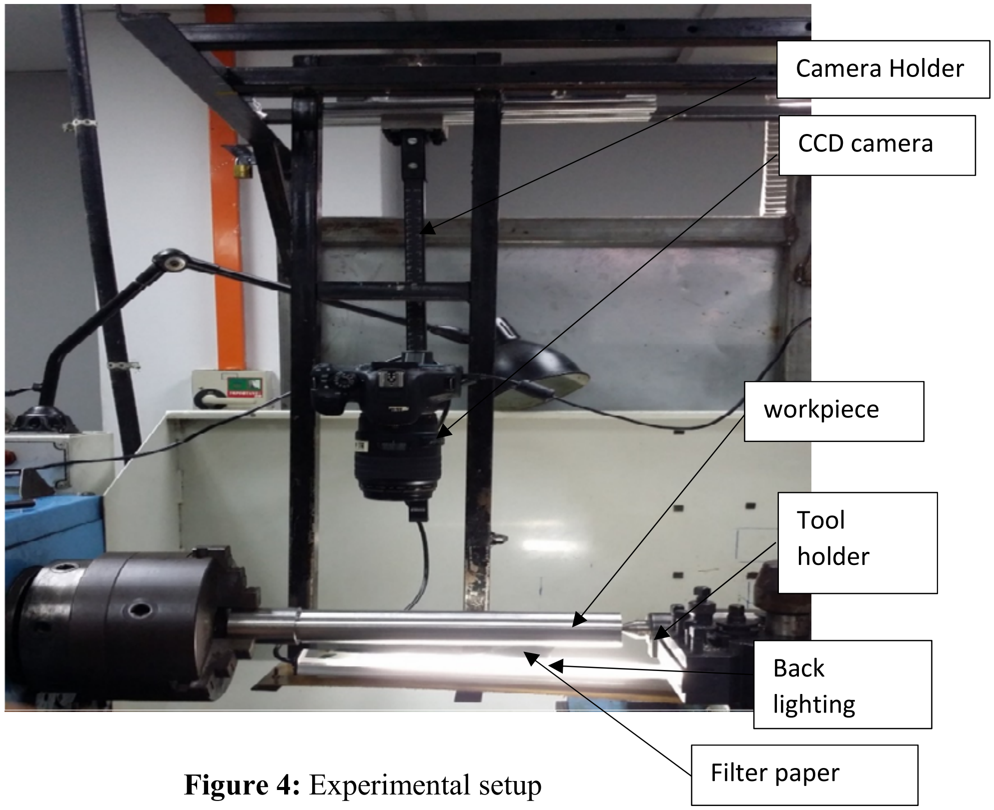


Figure 4: Experimental setup

3.0 Result and Discussion

The image of the surface profile was tabulated to observe changes in the profile. In Table1, image of the profile fd= 0.2 and fd=0.3 were tabulated with the number of passes. Since the changes on the surface profile is microscopic, CWT was used. As shown in above table, there was a gradual change in the profile from 1^{st} to 10^{th} pass. For fd=0.2, an obvious surface change recorded between 5^{th} and 6^{th} pass. From the 6^{th} pass, the surface had the significant difference in the waviness along the profile. While, the variation between the surface was clearer along the 10 passes in fd=0.3. After the 2^{nd} pass, the peak of the profile reduced until the 10^{th} pass. The profile began to has irregularities region along the surface from 5^{th} to 8^{th} pass. At last three passes for both fd, surface profile had obvious affect that indicate the worn cutting tool.

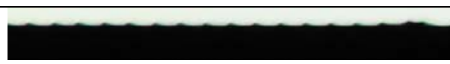
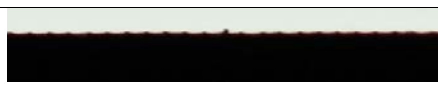
Pass	Feed rate 0.2	Pass	Feed rate 0.3
1.		1.	
2.		2.	
3.		3.	
4.		4.	
5.		5.	
6.		6.	
7.		7.	
8.		8.	
9.		9.	
10.		10.	

Table 2: Table shows the surface profile from all passes for fd= 0.2 and 0.3.

In this paperwork, four wavelets were used to read a very small change in the profile. Those are Morlet(Morl), Mexican Hat(Mexh), Symlets 30(Sym30) and Daubechies 40 (DB40). The range of the coefficient scale was 1 to 64. In this study, the scale divided into 4 equal regions. The results of different wavelet correspond to the coefficient values of the surface profile were plotted for the fd =0.2. This plot aided in choosing the best wavelet to study the surface profile, which affected by the tool wear.

3.1 Scale 16 plots of fd=0.2

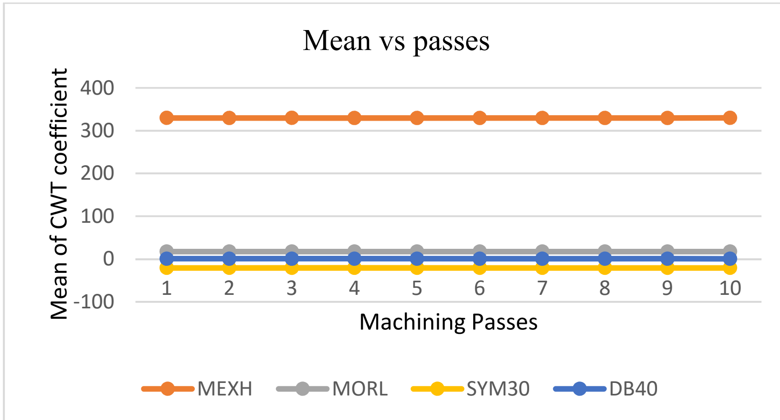


Figure 5: Mean of CWT coefficient vs machining passes

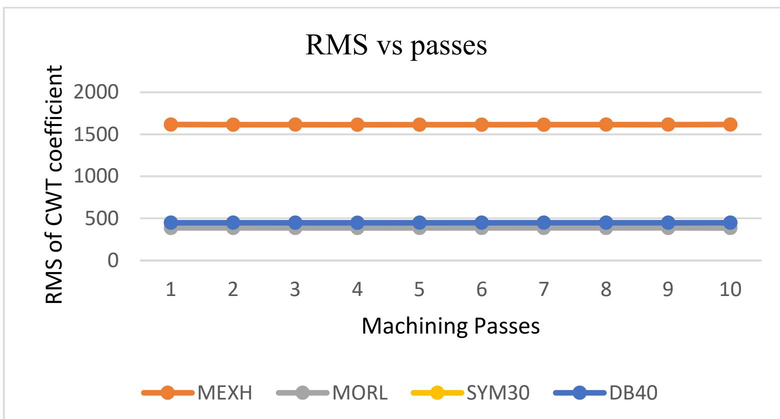


Figure 6: RMS of CWT coefficient vs machining passes

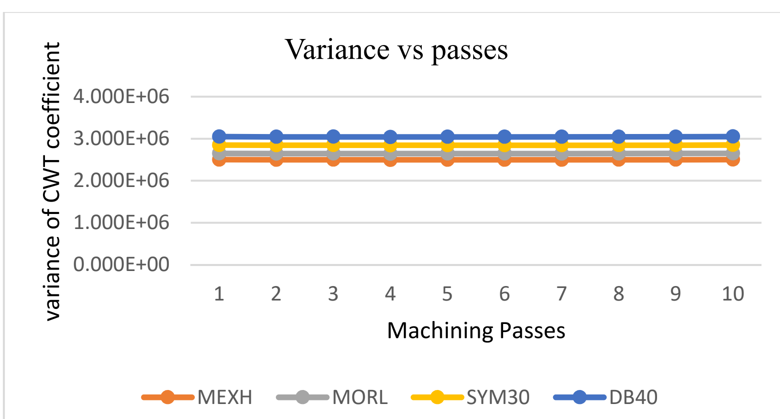


Figure 7: Variance of CWT coefficient vs machining passes

Figure 5,6, and 7 showing the plotted data of CWT coefficients values vs machining passes at scale 16. Based on figure 5, 6, and 7, the highest deviation within the data was observed. It is found that the data of scale 16 has the small change in the plot. This is due to scale 16 is very small and all the 4 wavelets has very least amount correlation with the original profile's plot. There was no trend in the plot to correlate with the worn tool. In short, scale 16 is an inaccurate scale to represent the surface profile with the coefficient values.

3.2 Scale 32 plots of fd=0.2

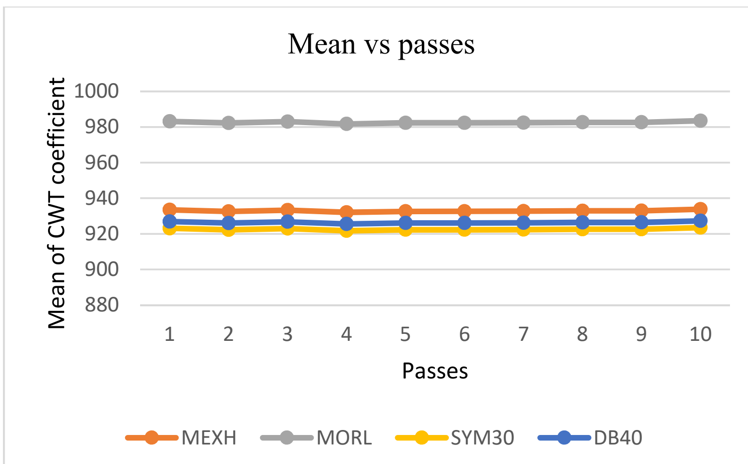


Figure 8: Mean of CWT coefficient vs machining passes

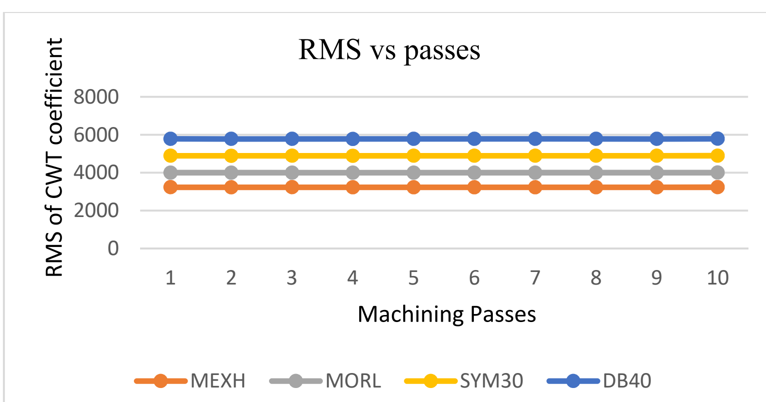


Figure 9: RMS of CWT coefficient vs machining passes

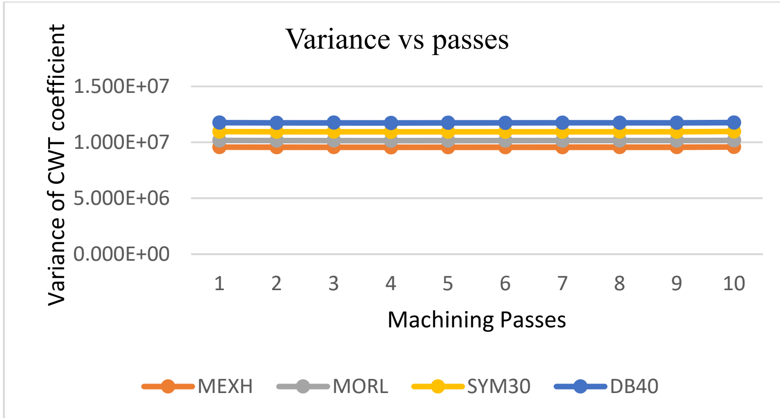


Figure 10: Variance of CWT coefficient vs machining passes

Figure 8,9, and 10 showing the plotted data of CWT coefficients values vs Machining passes at scale 32. Based on the figures, the highest deviation within the data was observed. It is found that the data of scale 32 has the small change in the plot. There was no trend observed in the plot to correlate the worn tool. In short, scale 32 is an inaccurate scale to represent the changes in the coefficient values.

3.3 Scale 48 plots of fd=0.2

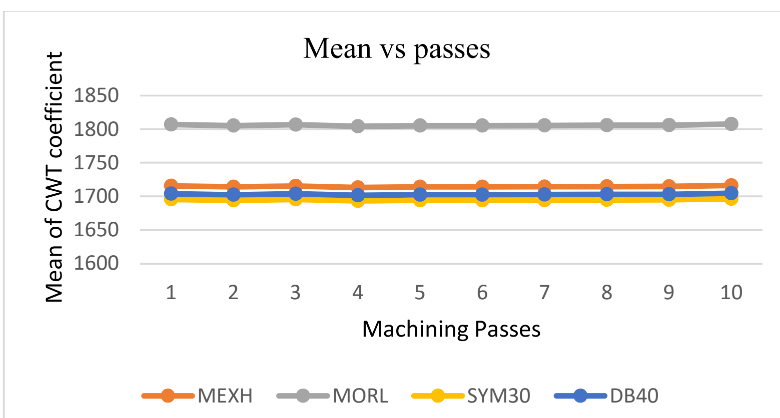


Figure 11: Mean of CWT coefficient vs machining passes

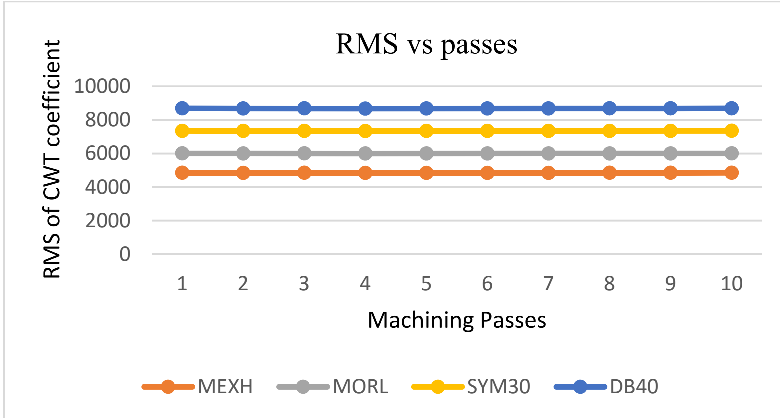


Figure 12: RMS of CWT coefficient vs machining passes

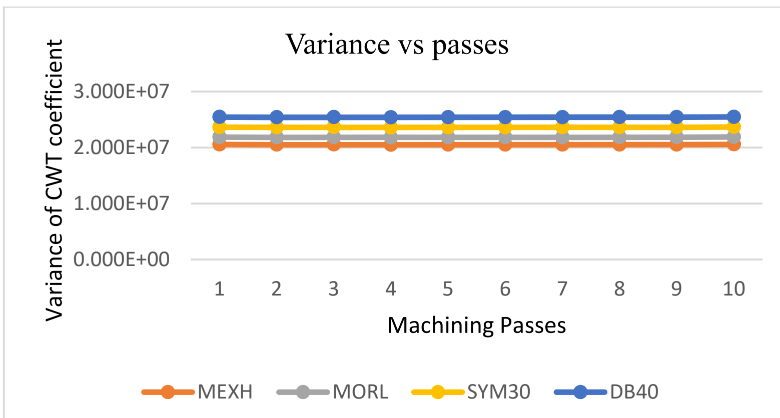


Figure 13: Variance of CWT coefficient vs machining passes

Figure 11,12, and 13 showing the plotted data of CWT coefficients values vs machining passes at scale 48. Based from the Figures, the highest deviation within the data was observed. With scale 48, the highest deviation of the coefficients values was found on the Figure 13. While other coefficient values showing the same trend as scale 16 and 32.

3.4 Scale 64 plots of fd=0.2

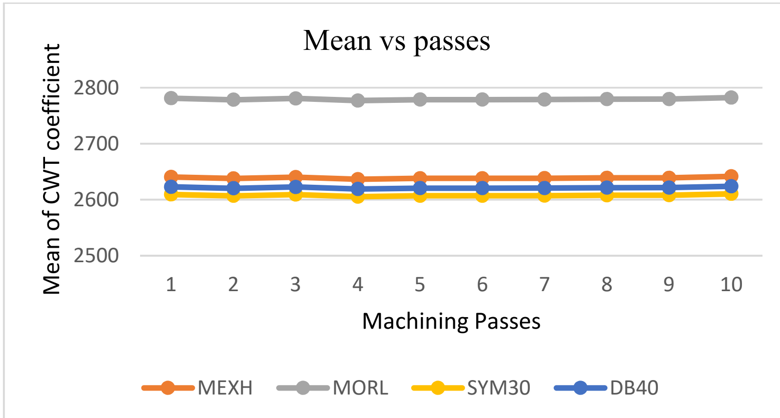


Figure 13: Variance of CWT coefficient vs machining passes

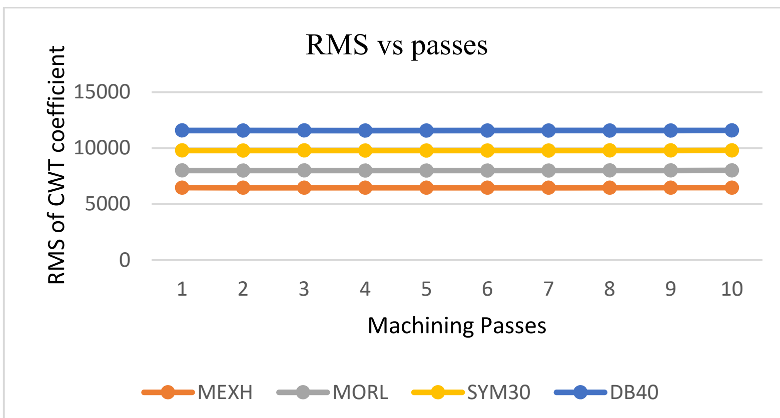


Figure 15: RMS of CWT coefficient vs machining passes

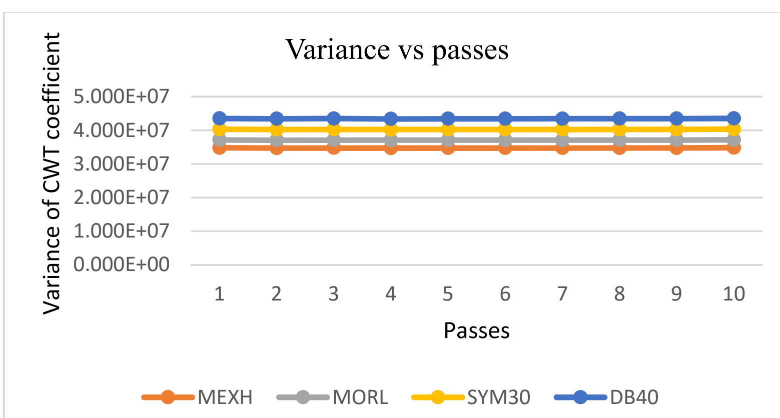


Figure 16: Variance of CWT coefficient vs machining passes

Figure 14,15, and 16 showing the plotted data of CWT coefficients values vs machining passes at scale 64. Based on Figures, the highest range within the coefficients values was found in RMS and Mean plot. From Figure 5 to 16, all the plots were inspected and among all the wavelets, Mexh is only wavelet that showed highest deviation in the coefficients values. From all the plots, mean of CWT coefficient profile at scale 64, Variance of CWT coefficient at scale 48, and RMS of CWT coefficient at scale 64 were chosen to analyse the turned surface profile that captured using the CCD camera. The chosen wavelet, scale and the CWT coefficient values were plotted separately to see clearer.

3.5 Plots of chosen wavelet, scale, and the coefficient values of the surface profile of fd=0.2

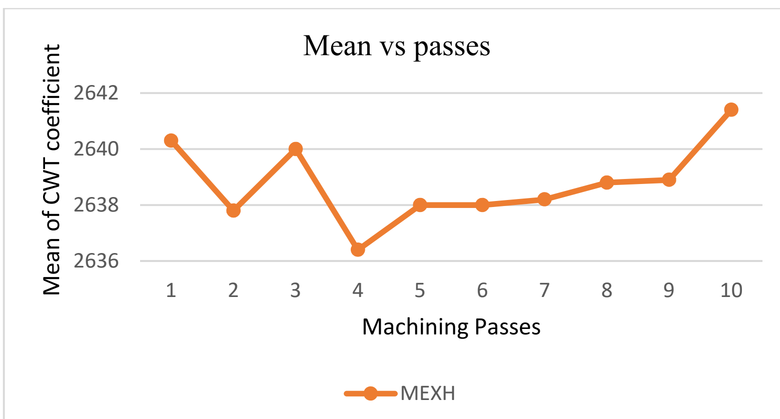


Figure 17: Mean of CWT coefficient vs machining passes at scale 64

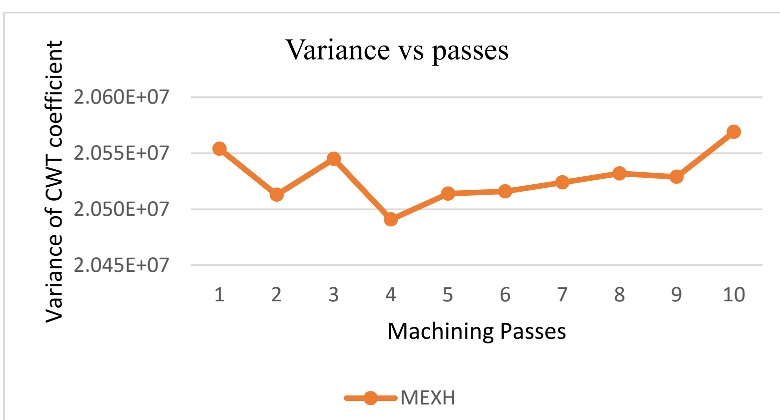


Figure 18: Variance of CWT coefficient vs machining passes at scale 48

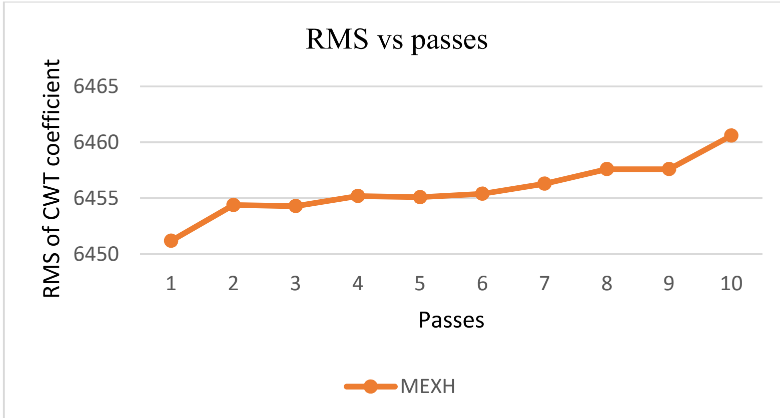
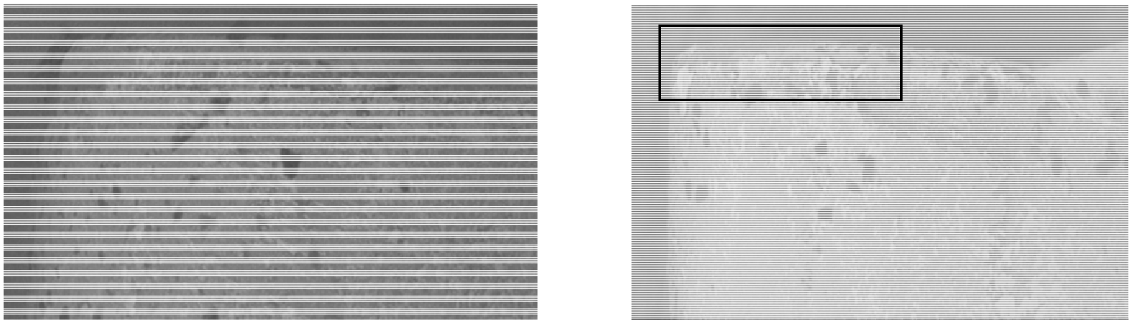


Figure 19: RMS of CWT coefficient vs machining passes at scale 64

Figure 17 is the plotted data of Mean of CWT coefficient vs machining passes at scale 64. Figure 18 showing the plot of Variance of CWT coefficient vs machining passes at scale 48**.** Mean and Variance plots are fluctuating in a same shape as shown in Figure 17 and 18. Both mean and variance showing a rapid increase after the 4th passes. Before the 4th passes in Figure 17 and 18, CWT coefficients values fluctuate which makes mean and variance not suitable to study the effect of tool wear on tuned surface profile. Although Mexh showed highest data range, but the plots do not have any conclusion to be made except for Rms. Figure 19 is showing the RMS of CWT coefficient vs machining passes at scale 64. From 1st to 2nd pass, the is a significant change in RMS values of the surface profile. This is due to the cutting depth used was 1.2mm, almost the maximum capability of the cutting tool.

During the 1st and 2nd passes, the initiation of the tool wear was bigger which leads to drastic change in RMS values in between both passes. In the 2nd pass to 9th passes, the RMS value did not have any sudden by inclined constantly. At last, the 10th pass has a noticeable change in the RMS value. To relate Figure 19 to the condition of cutting tool, cutting tool before machining and after 10 passes were compared.



(a) (b)

Figure 20: Scanned cutting tool for fd=0.2: (a) Before machining, (b) after 10 passes.

Figure 20 comparing the cutting tool before machining and after 10 passes. The black box in Figure 20(b), pointing the worn region of the cutting tool after the tool had turned the stainless steel for 10 passes. Here, Figure 20 and Table 2 proving that the cutting tool was worn after the 10th pass. Hence, the CWT coefficient values must show a relationship between the plots as gradual rise or fall in the values. Figure 19 shows a clear relationship between the RMS of CWT coefficient and the machining passes, where the RMS value of the increased along the machining passes.

To ensure that the RMS value of the CWT coefficient with Mexh at scale 64 is the best wavelet for extract information of the surface profile regards the effect of tool wear, the same plots as Figure 17,18 and 19 were plotted using data of fd=0.3.

3.6 Plots of chosen wavelet, scale, and the coefficient values of the surface profile of fd=0.3

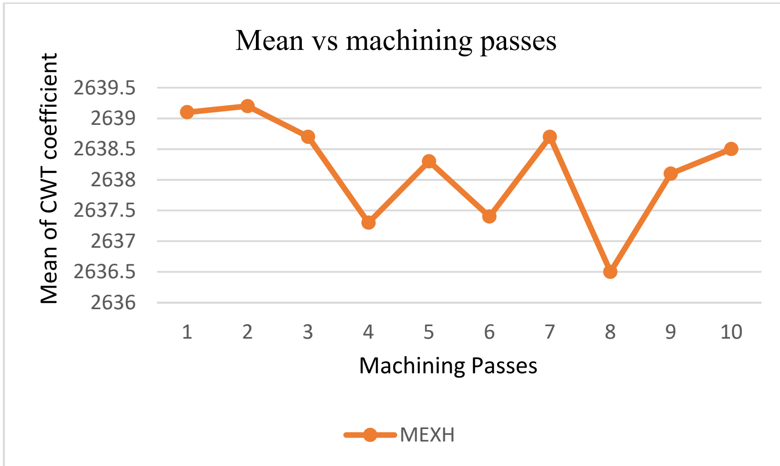


Figure 21: Mean of CWT coefficient vs machining passes at scale 64

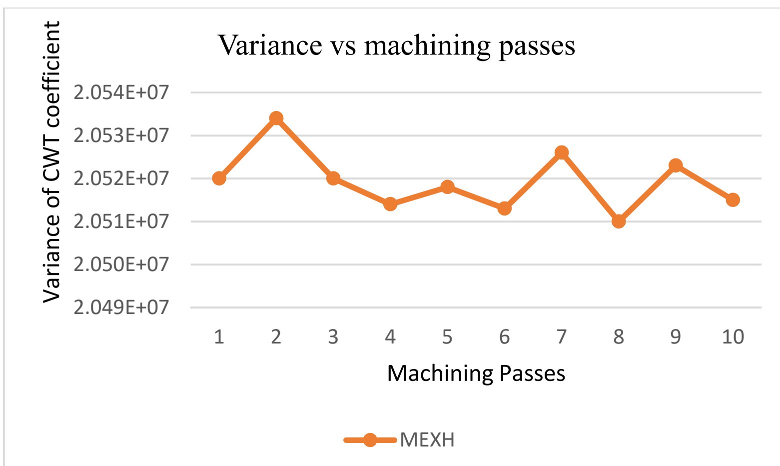


Figure 22: Variance of CWT coefficient vs machining passes at scale 48

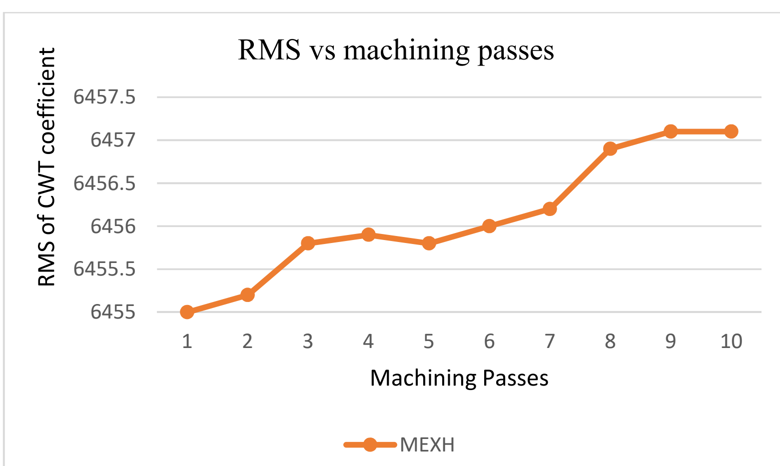
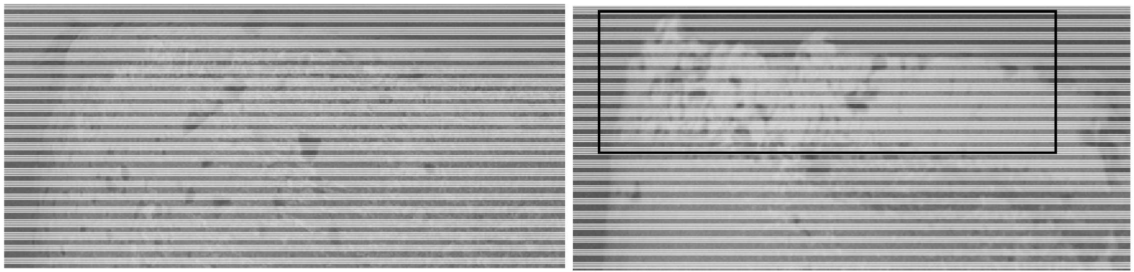


Figure 23: RMS of CWT coefficient vs machining passes at scale 64



(a) (b)

Figure 24: Scanned cutting tool for fd=0.3: (a) Before machining, (b) after 10 passes.

It can be concluded as the same way as for fd=0.2, but the variance fluctuates along all passes. Figure 21 showing the plot of Mean of CWT coefficient vs machining passes at scale 64 with fd=0.3. The shape of the plot fluctuates severely compare to Figure 17. While, Figure 22 is the plot Variance of CWT coefficient vs machining passes at scale 48 with fd=0.3. Despite the mean and variance in Figure 17 and 18 are not suitable for this paperwork, but they still showed a partially better result compared to Figure 21 and 22. With fd=0.3, the variance is not having any linear relationship with the passes. As for mean in Figure 21, 1^{st} to 4^{th} passes dropping quadratically and unstable until 9^{th} pass. During 10^{th} pass, the reading shows there is a moderate increase.

Figure 23 showing the RMS of CWT coefficient vs machining passes at scale 64. RMS shows the same statement as the Figure 19. But, there is no rapid increase for the 1^{st} and 2^{nd} passes. The high initiation of tool wear starts from 2^{nd} to 3^{rd} passes. The shape of the plot looks symmetrical. After the 5^{th} passes, the shape of the plot continues the same as before 5^{th} passes but increased in values. At 10^{th} the tool wear remains the same after the 9^{th} passes. The shape of the plot in Figure 24 comparing the cutting tool before machining and after 10 passes. The black box in Figure 24(b), pointing the worn region of the cutting tool after the machining process.

Figure 24 and Table 2 proving that the cutting tool was worn after the 10^{th} pass. Thus, coefficient values of the surface profile must show a relationship between the plots as gradual rise or fall in the values. Figure 23 shows a clear relationship between the RMS of CWT coefficient and the machining passes, where the CWT coefficient rise symmetrically along the machining passes.

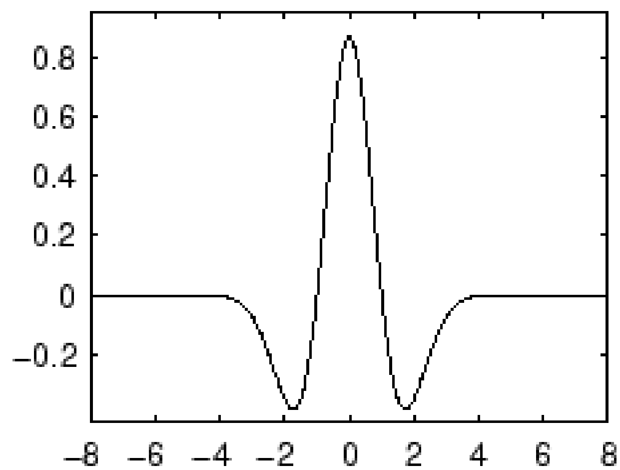


Figure 25: Showing the shape of Mexican wavelet profile

Figure 25 represents the shape of the Mexican wavelet. The reason for Mexican Hat has been an accurate wavelet in this study, is because of the shape of the wavelet itself. If this wavelet is scaled at 64, the shape will be broader and the profile would be almost like workpiece of the surface profile. As shown in above Figures, the other wavelets are not suitable to observe the changes in the surface profile, perhaps these wavelets might functional to another purpose of study.

4.0 Conclusion

In this study, two experiments in lathe machine has been carried out with fd=0.2 and fd=0.3. The images of the surface profile of the above feed rate were tabulated. Then with the data, Continuous Wavelet Transform (CWT) has been applied on this data. Four types of wavelets have been used in this paperwork. The major task is to inspect which type of wavelet is best to study the effect of tool wear on the turned surface's profile. From what had been figured and tabulated, Mexican hat (Mexh) was the preferable wavelet to observe the effect of the tool wear on the turned surface. This conclusion is made stronger by the two set of results, figure 19 and 23 where the RMS of CWT coefficient vs machining passes with Mexh at scale 64 shows the similar and best results even with the different feed rate. Hence, as for the effect of the tool wear on the surface profile, the RMS of CWT coefficient has shown a clearer correlation where the coefficient increases along the machining passes.

5.0 References

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