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Stochastic Distribution of Wear of Carbide Tools during Machining Operation of Welded Flank Joints

Joseph I. Achebo

Department of Production Engineering
University of Benin, Nigeria

Abstract

The increasing awareness of wear of carbide tools during machining operation has created doubts about the ability of this tool material to withstand stress and strain induced by the machining process. Manufacturers are beginning to question their dependence on carbide tools, seeing that they no longer meet their expected designed life. The stochastic point model was used to determine the rate of wear distribution of the carbide tool material and the reliability of wear resistance of the cutting tool. At pre-determined times, cutting speeds and feed rates during machining operations were used to generate the machining parameters that were used to calculate for the welded flank joint wear and the reliability of tool resistance to wear. It was found that at 850 rpm, a 15146 mm^3 volume of metal was removed creating a flank wear distribution and corresponding reliability. As the flank wear reached 0.3 mm, machining operation stopped. This process lasted for 540 seconds. The corresponding reliability of the tool ability to resist wear was 0.06. It was concluded that the critical flank wear is at 0.3 mm. From the analysis, the wear distribution of the welded flank joint is not normal. This study has successfully analyzed the wear distribution pattern of carbide tool material during the machining process.

Keywords: cutting speed, feed rate, machining time, tool life, reliability, wear.

1. Introduction

Hayajneh et al [1] has stated that Chen and Smith [2] said that metal cutting is one of the most significant manufacturing process in the area of material removal and Black [3] defined metal cutting as the removal of metal chips from a workpiece in order to obtain a finished product with the desired attributes of size, shape and surface roughness. Noordin et al [4] defined machinability as a combination of optimum machining removal rate, good surface integrity, accurate and consistent workpiece geometry characteristic, lower wear rate and acceptable chip formation.

The increase in the efficiency of machining operations has lead to the development of new technologies used for integrating design into manufacturing processes hence the invention of High Speed Machining (HSM) process. Brezocnik et al [5]; Nandi [6] and Elmagrabi et al [7] were of the opinion that HSM tools are currently being used in the manufacturing sector, as Lin [8] puts it, HSM increases production efficiency and reduces machining time. Bachacz [9] observed that the greatest concern of most researchers during the conceptualization, product development and design process on these machines is the machine's efficiency and reliability [10]. Since the use of high spindle speed machine technology should reduce time spent on a workpiece, productivity is also increased and the reliability of tool resistance to wear is expected to reduce.

Tool wear is a significant factor because if left unchecked it is a major cause of dimensional inaccuracy in workpiece machining operation. In a continuous machining operation large pieces of metal fillings are removed from the workpiece as a result of the frictional contact with the cutting tool thereby inducing wear on the tool, in respect of the amount of carbon content. The carbon content is itself responsible for tool hardness.

As tools wear, irregularly shaped cuts appear which could distort the micostructural arrangement of the workpiece material. If the cutting tool experiences further wear, the cutting efficiency reduces significantly and precipitously. Bonjelbene et al [11] and Petropoulos [12] have stated that if neglected and left unchecked, continuous tool wear will cause poor dimensional accuracy and the deterioration of the surface integrity of the workpiece, invariably leading to eventual damage of workpiece [8].

Some researchers have studied the effect of wear on tool life during machining operations [13]-[15]. In this study, the stochastic distribution of wear rate of carbide tool during machining operation was studied. This study lead to the determination of machining parameters that lead to welded flank joint wear rate.

Corresponding authors: ***Joseph I. Achebo: E-mail**:* josephachebo@yahoo.co.uk, Tel. +2348035534521

I Research Methods

In accessing the life of a Tungsten Carbide cutting tool. The spindle speed, torque and power used in determining tool life were investigated. Chapman [16] proposed some equations for determining the machining parameters as followings.

The spindle speed, N is calculated in min/rev. By applying (1)

$$N = \frac{L}{f} \tag{1}$$

Where L = shaft length in mm and f = feed in mm per rev. N can also be calculated by using (2)

$$N = \frac{1000S}{\pi d} \tag{2}$$

Where S = cutting speed in m/min and d = workpiece diameter in mm

The speed generates the torque that turns the cutting tool. The torque, T is calculated by using (3)

$$T = C.f^{0.75} d_d^{1.8} \tag{3}$$

Where C = a constant depending on the material; for mild steel = 0.36 and d_d = diameter of drill

The power, P that is used to overcome the resistance offered by the workpiece and the twisting effort used to turn it, is calculated by using (4).

$$P = \frac{2\pi NT}{60000} \quad (kW) \tag{4}$$

The volume of metal, R removed per minute

$$R = A_h fN \quad \left(mm^3\right) \tag{5}$$

Where A_h = area of hole

Then, the energy consumed, E_p therefrom is calculated by using (6)

$$E_p = \frac{R}{P} \quad \left(mm^3 / joule\right) \tag{6}$$

Speed and spindle system deflection affects tool life. It either blunts the tool due to high speed or breaks it due to deflection. However, the relationship between cutting speed and tool life is expressed by (7).

$$VT^n = C \tag{7}$$

Where V= cutting speed in m/min, T = tool life in min and C is a constant depending on cutting conditions.

$$n = \tan\phi = \frac{\log V_1 - \log V_2}{\log T_2 - \log T_1} \tag{8}$$

But n has been experimentally determined to be $\frac{1}{5}$ for roughing cuts in steel and □ = slope angle when the cutting speed is plotted against the tool life.

An approximate equation relating tool life to Brinell hardness number is

$$K_i = VT^n f^n d^n BHN^{1.25} \tag{9}$$

K_i = 556 is a constant obtained from machining operation experiments

Where

$$BHN = \frac{P_L}{\frac{\pi}{2} D_i \left[D_i - \sqrt{D_i^2 - d^2} \right]} \tag{10}$$

and BHN = brinell hardness number, P_L = applied load of 3000kg, D_i = diameter of indenter usually 10 mm and d is the diameter of depression in mm measured with the aid of a pre-calibrated microscope

Reliability Calculation

The reliability equations as treated by Lin [8] are presented in (13) – (15)

If E (X) is the expected value of the entire flank wear, then

$$E\left(X\right) = \sum_x X \quad p(x) \tag{11}$$

Therefore, the standard deviation would be

$$\sigma = V\left(x\right) = E\left(x - \mu\right)^2 = \sum_x \left(x - \mu\right)^2 p\left(x\right) \tag{12}$$

σ = standard deviation of average flank wear normal distribution.
Mean time to failure – free operation, T_o is given by

$$T_o = T_v \exp\left[\frac{\sigma^2}{2}\right] \tag{13}$$

where T_v is the time when average flank wear reach the critical flank wear value, V_B^* = 540 seconds
Variance of life length

$$Var(\tau) = T_o^2\left[\exp\left(\frac{\sigma^2}{2}\right) - 1\right] \tag{14}$$

The failure rate of the cutting tool is given as

$$\lambda(t) = \frac{1}{\sqrt{\mathrm{var}(\tau)}\sigma}\exp\left[\frac{T - T_o}{\sqrt{\mathrm{var}(\tau)}}\right] \tag{15}$$

Reliability, $$R = e^{-\lambda t}.CF \tag{16}$$

CF = correction factor = 1.7. This factor takes into consideration some machining deficiencies encountered during the machining operations. In the determination of the reliability tool resistance to wear. The flank wear taken as the failure rate and the mean time to failure was calculated to be 9 mins.
In the case of reliability calculation, the failure rate was taken as the flank wear, ω
Lin [8] expressed the equation for ω, as

$$\omega = cV^{b1} f^{b2} t^{b3} \tag{17}$$

Where c, b_1, b_2, and b_3 were experimentally determined to be 0.36, 0.2, 1.56 and 0.25 respectively

II DISCUSSION OF RESULTS

A 560 watts CNC lathe machine was used to machine a welded flank joint of 10mm. The diameter of the tool drill, a fixed depth of cut and a mechanical test result of the flank BHN were used for investigating the reliability of the tool resistance to wear and tool life are shown in Table 1. The spindle speed obtained was 850 rpm which falls within the range of speed of 750-1500rpm used by Hayajneh et al [1] and possess a torque of 6.24 Nmm for turning. The volume of metal removed from the flank is 15146mm^3 whereas the energy consumed there from was 25 mm^3 /joule. The tool life was estimated to be 9mins. Different cutting speeds set at corresponding feed rates as shown in Table 2 were used for the experiment to determine the machining times and calculate for the corresponding welded flank joint wear and reliability The result is shown in Table 2. Lin [8] in his report showed that as the flank wear reaches 0.4mm, machining operation stopped. This shows that at 0.4mm, further machining operation would increase the wear and eventually put the flank in a situation where it can not be re-grinded or rebuilt and may no longer be relevant for use. Therefore the determined threshold value indicates the critical value.

From the Table 2 as the cutting speed increases the machining time reduces, but consequentially, the tools propensity to resist wear also reduces. This however, indicates that the more the tool is subjected to machining operation, the more susceptible it is to wear. This argument is also supported by Sanglam et al [17] saying that high cutting speed and feed rate will induce higher stress which would eventually promote wear.
In this study, the critical flank wear is between 0.3 and 0.4mm. But for accuracy of result, emphasis was more on 0.3mm. This is because further machining process above 0.3mm may render the welded flank useless; the wear of the flank would have been at a critical stage where it can no longer be reused.

Table 1: Parameters used for calculation

$Diameter\ of\ drill = 5.5mm$
$BHN\ of\ AI5I\ steel = 230$
$Depth\ of\ cut\ is\ at\ 0.15mm$

Table 2: Machining parameters

Cutting speed, V $(m/\min)$	Machining time (s)	Feed rate (mm/rev)	Calculated flank wear (mm)	Calculated reliability of tool resistance to wear (R)	Tool failure rate (λ)
300	1200	0.05	0.06	0.5800	$1.35x10^{27}$
350	800	0.10	0.17	0.2200	$3.47x10^{10}$
400	540	0.15	0.30	0.0600	0.569
450	310	0.20	0.41	0.0250	$1.64x10^{-10}$
500	260	0.25	0.60	0.0045	$1.38x10^{-12}$
400	622	0.15	0.15		

Conclusion

This study was done to determine the welded flank joint wear rate and its reliability to resist wear. These parameters lead to the determination of tool life. From the numerical analysis, the critical flank wear value was reached. Beyond this wear the flank value is expected to be un-restored or unfit to be grinded for reuse. From the experimental analysis the critical time when flank wear reaches its critical value was obtained. This value corresponded with the tool life obtained using numerical methods as expressed by (9). The variation of flank wear as it relates to various machining parameters was also studied and measured and this is shown in Table 2, as the flank wear increases, the feed rate and cutting speed also increase whereas machining time and the reliability of the tool resistance to wear reduce due to the pressure exerted on the tool by the process parameters mentioned here. This pattern of flow of the process parameters has been reported by other investigators[8,9]. In this study the stochastic distribution of the wear profile of carbide tools during the machining operation of welded flank joints has been successfully investigated.

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