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Effect of Machining Parameters on Hole Quality of Micro Drilling for Brass

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Abstract

This paper present the effect of drilling parameter such as spindle speed, feed rate and drilling tool size on material removal rate (MRR), surface roughness, dimensional accuracy and burr. In this work, a study on optimum drilling parameter for HSS drilling tool in micro-drilling processes in order to find the best drilling parameter for brass as a workpiece material. Micro drilling experiment with 0.5 mm to 1.0 mm drill sizes were performed by changing the spindle speed and feed at three different levels. The results were analyzed using microscope and surface roughness device. Comparatives analysis has been done between surface roughness, MRR and accuracy of drilled holes by experimentation. From the result, the surface roughness are mostly influenced by spindle speed and feed rate. As the spindle and feed rate increases, the surface roughness will decrease. The tool diameter gives less influence on the value of surface roughness. The value of MRR is decreased when the tool diameter, spindle speed and feedrate are decreases. As drilling tool diameter, feedrate and spindle speed increase the dimensional accuracy of drilled hole will decrease. The increment of spindle speed and feed rate value mostly will affect the tool wear and size of burr on the edge of drilled holes.

Keywords: Micro drilling, Surface roughness, Material removal rate, Dimensional accuracy

1. Introduction

Drilling is one of the most fundamental machining technologies and is moving toward high precision/high speed applications for productivity enhancement. The drill tools play a critical role is increasing the productivity of a cutting process. Although the price of a cutting tool itself is relatively low, the costs caused by tool failures are considerably higher. Therefore, from the viewpoint of cost and productivity, modeling and optimization of drilling processes are extremely important for the manufacturing industry (S.A. Jalali, 1991). The poor removal of chips in deep drilling of small diameter is often the cause of tool breakage and poor quality surface. There are a lot of studies being conducted in area of drilling in order to identify a machinability of drilling. These studies include in the area of modeling of drilling process, vibration drilling, twist drill shape, modeling of drilling tool, tool wear, surface roughness, burr formation (B.Y.Lee,1998, S.Arula,2006, A.S.Salama,1996, H. Hocheng, 2006, F.H. Jung, 2002, C. Sanjay,2005, M. Gerard,1999). Researchers also have interest in micro drilling of metal and not only for printed circuit board.

R. Mauri and S. Matti, (1995), study a tool wear and failure in the drilling of stainless steel. The main result of the tests with different drill materials found that expensive bright drills with or without TiN-coating had a lower productivity compared to cheaper black drills. This is due to the low feed rate values causing a strong decrease in the chip flow rate. The on-line measurement result show that all the quantities measured remain at an almost constant level during the entire tool life-time until the hole in which the drill totally fails. Y.C. Chen and Y.S. Liao (2003) study on wear mechanisms in drilling of Inconel 718 superalloy. This is done by conducting a drilling experiment with the use of the cutting fluid containing the nano-particle low friction surface modifier are conducted. It is found that the service life of the drill is lengthened significantly and indirectly reducing the machining.

One notable drilling technology, micro-hole drilling, is becoming increasingly more prominent in various precision industries, such as the production of automotive fuel injection nozzles, watch and camera parts. From several micro-hole-making methods, mechanical drilling is widely used because it is more independent of workpiece properties, subject to less thermal deformation, and minimizes finishing work. Thus micro-drilling can generate deeper holes with better straightness, better roundness and smoother surfaces. On the other hand, micro-drilling methods suffer from a number of difficulties. To get a better finishing for drilled holes, many factors need to be considered such as material, spindle speed, feed rate and tool diameter. Therefore, in the present commercial market, micro-drilling remains the operation of choice for the drilling of microholes.

It has been reported that even very small variations in the geometry of the drill point can have a very significant influence on the performance of the drill. Hence, the drill point geometry, which is uniquely defined by the shapes of the flute and flank surfaces, is a primary factor to be considered when attempting to improve the drill's machining performance. Due to its small physical size, conventional point geometries such as conical, spiral, cylindrical and multi-facet cannot be reproduced on micro-drills. Currently, micro-drills with planar point geometries are prevalent in industrial practice (C. Lin et al, 1992). However, this particular type of micro-drill has an extremely low heel clearance angle distribution along the intersection line of the primary and secondary flanks.

E. Kai and M. Katsumi, (2002), fabricate a three-dimensional and high aspect ratio of micro-shape. This is done by using micro-drilling on monocrystalline silicon using a small drilling tool. The smallest machinable hole achieved was of 6.7μm diameter. Furthermore, an aspect ratio is more than four was obtained in the drilling of a 22μm diameter and 90μm deep hole. S.C. Man, et al (1999), identifies the control for micro-drilling productivity enhancement. Therefore, a method for cutting force regulation was proposed to achieve continuous drilling. A proportional plus derivative (PD) and a sliding mode control algorithm are implemented and compared for controlling the spindle rotational frequency. Experimental results will show that sliding mode control reduces the nominal torque and cutting force and their variations better than PD control, resulting in a number of advantages, such as an increase in drill life, fast stabilization of the wandering motion, and precise positioning of the holes.

H. Nakagawa et al, (2007) has carried out surface roughness testing of a drilled hole wall. It was increases as drill temperature increases during drilling. Drill temperature tends to increase with the workload on the drill caused by the friction between the hole wall and the land or margin of the drill, regardless of drilling and material conditions. Therefore, a reduction in the workload caused by friction is effective for improving the quality of micro-drilled holes. K. F. Ehmann and H.C. Chyan (1997) have developed a curved helical micro-drill point technology for micro-hole drilling. The drill point is the most important part of the drill which penetrates into the material of the workpiece during the machining process. The geometry of the drill tip is such that the normal rake and clearance angles and velocity of the cutting edge vary with the distance from the center of the drill. Even small variation in geometry or symmetry errors can have a very strong influence on the performance of the drill. The geometry of the point, uniquely defined by the shapes of the flute and flank surface, is the primary factor determining performance.

Z. Yang, (1998) be able to increase the micro-drilling reliability by using vibrating drilling. By comparing with ordinary drilling, the life-time of the micro-drill used under vibrating drilling conditions has different types of distributions. Vibrating drilling appears to increase reliability of the micro drill, embodying a life-time increase and scatter reduction. Wear reduction is an essential reason for increasing the reliability of micro-drill during vibrating drilling. G.L. Hak, (2004), had studied the tool life model for the micro-drill during wet micro-drilling of ceramic green body. The model predicted very well the axial force of micro-drill. From the modeling of chip flow for the worn-out micro-drill tip, the large wear on the side of micro-drill tip induced the rapid increase of the axial force during wet micro-drilling of ceramic green body, which could be used to determine the tool life of micro-drill. The model could also predict the number of micro-holes that could be drilled within the tool life of micro-drill.

The quality of drilling is too important in order to retain the industrial advantage for micro-drilling technologies over rival manufacturing processes. The aim of this work is to study an optimum drilling parameters for High Speed Steel (HSS) drilling tool in micro-drilling processes by analyzing their surface roughness, dimensional accuracy and burr formation. The cutting parameters that will be considered are spindle speed, feed rate and tool diameter for brass.

2. Experimental Design

The micro drilling experiment was conducted using DT110 Multi purpose Micro-Machine from MIKROTOOL Pte Ltd. There are three machining parameter that had been put into consideration of this experiment which is drilling tool size, spindle speed and feed rate. These parameters have large influences on the investigation result in the previous researches. HSS drilling tool is used in this project with starting diameter 0.5mm to 1.0mm with increment of 0.1mm. Example of drilling tool is shown in figure 1. 1000, 2000 and 3000 rpm is chosen as rotation drilling speed and the feed rate are set as 1, 5 and 10 mm/min. Brass was used as work material in this experiment. It is an alloy consists of copper and zinc. The material selected is chosen based on their characteristic such as brittle, ductile and hardness. The block size of brass is 40mm x 40mm x 10mm for length, width and thickness respectively. The drill hole on brass workpiece is shown in figure 2.

The performance of drilled holes are been measure in term of surface roughness, MRR and dimensional accuracy. In order to observes and measure the quality of surface finish on the machined surface, ICAMSCOPE light microscope and Perthometer Mahr PFK Model M4Pi with a styles type of flexible surface texture profiler was used. The surface roughness is a term used to describe the geometry quality of a mechanical surface. The quality of the surface roughness is importance in the evaluation of the machined surface. There are two method of measuring the surface roughness of material which is the arithmetic mean value and the root mean square value. Only the Arithmetical Mean Roughness, ***Ra*** parameter is selected to be measured the surface roughness. The ***Ra*** is an average or center line average of value. It is based on the schematic illustration of a rough surface. The arithmetic mean value is defined as [8]:

$$Ra = (a + b + c + d + \dots\dots + n) / N \quad (1)$$

Where all coordinate, a,b,c,…..,n are absolute value, and the N is the number of reading. The lowest value of ***Ra*** means that the surface is smoother. The MRR was calculated using model developed by B.Y. Lee et al, (1996). The MRR is:

$$MRR = \frac{\pi D^2 f N}{4} \quad (2)$$

Which, MRR = Metal removal rate

D = Drill diameter [mm]

f = Feed rate [mm/rev]

N = Rotational speed of the drill [rpm]

$$N = \frac{1000U}{\pi D} \quad (3)$$

Which, U = Cutting speed [m/min]

Normal procedure of drilling process is using center drill to mark the location before drilling with selected tool diameter. In case of micro drilling or drilling with tool diameter less than 1 mm, there is no such center drill available. Therefore the programming G-code is carefully design to overcome the location marking problem in micro drilling. The micro drilling process starts with rotating drilling tool with 0.5mm/min feedrate moves to the workpiece and drill slowly with 0.05mm of repeated depth until it reached 1mm of depth on brass. Then the experiment starts with selected drill diameter, feedrate and spindle speed.

3. Result and Discussion

Machining time, MRR, surface roughness and dimensional accuracy are obtained from the experiment using the calculation and measurement device as shown in Table 1. From the results, for 0.5 mm drilling tool diameter, the tool breaks when the drill tool rotates at 3000 rpm and feed rate is 10 mm/min. Smaller drilling tool diameter rotates with higher rotation speed and faster feedrate will decrease their capability to withstand the drilling force. For a smaller drilling tool, smaller chip size was produce, therefore the chip is easily clogged inside the unfinished drilled hole and suddenly it will stick and break the tool. Also, from the Table 1, the time taken to finish the drill operations increases as feed rate is increases. In a logical sense, if the feed rate is increases, the time taken to finish the drill operation is faster.

The value of MRR is decreases when the tool diameter decreases as shown in table 1. The reason for this phenomenon is when the tool diameter is large; the force acting towards on the material also increases. So that the large diameter can removes more material in one second. The large tool diameter has a large flank on the tool. So the material can be removed through this flank easily.

For 0.5 mm tool diameter, the tool will break if the feed rate reaches 10 mm/min. It is because of smaller tool diameter and higher feedrate, the force acting toward the cut material will increase. The cutting tool will easily bend and break. Another theory was, the chip clog inside tool spiral, after some times the rotating force will increase and cannot rotates anymore, so suddenly it will break. For a smaller tool size, smaller chip size was produce. The generated heat for small chip is more compare to larger chip size, therefore, the chip easily hot and stick to the cutting tool edge. Then tool become blunt and will increase their rotating force.

3.1 Effect of Surface roughness on tool diameter, feedrate and spindle speed

The size of drilled holes are small, therefore the workpiece has to cut into half using EDM wire cut machine to allow portable profiler travel on the inside drilled surface. The effect of tool diameter in drilling process will affect the surface roughness as shown in figure 3. Generally, as the tool diameter decrease, the ***Ra*** value also decreases. It is because, larger tool diameter will cut more material compare to the smaller drilling tool size, therefore, drilling with small chip size will increase the ***Ra*** value. The same behavior also found for different feed rate. As the spindle speed increase and feed rate increase, the different on ***Ra*** value will decrease. It can be conclude that to achieve a lower ***Ra*** value for smaller tool diameter, increase the spindle speed and decrease the feed rate. Figure 4 show that the surface of the drilled holes using brass material for drill 1.0 with 2000 rpm and different feed rate. This image is taken under 100x using ICAMSCOPE. It is clearly seen that with the increment of feedrate, the surface are rougher. The effect of feed rate on surface roughness is shown in figure 5. Increasing the feedrate will increase the ***Ra***. For tool diameter 0.5mm with 3000 RPM and 10 mm/min feed rate, the tool will break during the drilling process. From the figure, it shows that increasing spindle speed and feed rate will give a very significant effect on surface roughness. It will reduce the value of surface roughness.

The accuracy of the holes drills is important in the drilling operation because in micro-drilling, a little bit of inaccurate holes drills will affect the inner surface roughness, dimensional accuracy and encourage a short of tool life. One of the factor that causing the inaccurate holes drills is vibration of the drilling tool. This is because of clamping on tool drills. Generally, to reduce vibration, the drill tool should be clamping with drilling length same as workpiece thickness. Longer drilling length will increase vibration; therefore it will reduce the dimensional accuracy. Dimensional accuracy for drilled holes is shown in figure 6. There are 5 to 10% error records from these experiments. If the tool drill clamped out of procedure, it will effect to the holes drills on burr on surface finishing.

The observation of drilling tool after experiment is done to identify the wear occurs on it cutting edge. Example of wear is shown in figure 7. The breakage drilling tool with diameter 0.5 mm is shown if figure 8. This drilling tool with diameter 0.5 mm will break while drilling with feedrate of 10 mm/min. It can be concluding that the smaller drilling tool diameter, the smaller feedrate require avoiding tool break.

3.2 Burr Formation

The burr formations are observed under different cutting condition, such as drill geometry, material properties, feed rate and cutting velocity. Burr can be observed at the entrance of drill and also form at the exit stage. Burrs are formed as the result of plastic deformation fracture. According to T. Miyake et al (1994), the burr can be classified into 3 type, burr without cap by fracture, burr with cap and burst burr without cap. Several effects on these materials are burr formation, inaccurate holes drills and the chip of the material removal still in the holes. Burr formation happened when incorrect tool clamped or maybe because of the material characteristic itself. Figure 9 shows a burr occur at the edge and its look like a bump around the edge. Thin phenomenon occurs on ductile material such as brass. The figure also show that a chip of the material removal still in the inside surface of drilled hole. Burr with cap occur at the exit drill is shown in figure 10. The similar phenomenon can also be found in macro size of drilled hole.

4. Conclusion

This study was done to find the effect of drilling parameter on surface roughness, MRR and dimensional accuracy of HSS micro drilling tool on brass. After data collection, analysis and discussion on the experiment, the optimum range of cutting parameter for micro drill with diameter 0.5 to 1.0 mm was 2000 to 3000rpm for spindle speed and for 5 to 10 mm/min feedrate. Based on the main objective of the study and the result from the experiment, several conclusions have been made;

1) The value of surface roughness are mostly influenced by spindle speed and feed rate. If the value of these spindle and feed rate increases, the value of surface roughness will decrease. The tool diameter gives less influence on the value of surface roughness.

2) The value of MRR is decreases when the tool diameter, spindle speed and feedrate are decreases.

3) For the accuracy of the holes drills, as drill diameter, feedrate and spindle speed increase the dimensional accuracy of drilled hole will decrease.

4) The increment of spindle speed and feed rate value mostly will affect the tool wear and size of burr on the edge of drilled holes.

References

A.S. Salama and A.H. E1Sawy, (1996). The dynamic geometry of a twist drill point, *Journal of Materials Processing Technology*, 56, pp. 45-53

B.Y. Lee, H.S. Liu and Y.S. Tarng, (1996). Modeling and Optimization of Drilling Process. Department of Mechanical Manufacture Engineering, National Huwei Institute of Technology, Huwei, 632, pp. 1-9.

B.Y. Lee, H.S. Liu and Y.S. Tarng, (1998). Modeling and optimization of drilling process, *Journal of Materials Processing Technology*, 74, pp. 149–157

C. Lin, S.M. Kang and K.F. Ehmann, (1992). Planar Micro-Drill Point Design and Grinding Methods, *Transactions of the North American Manufacturing Research Institution of SME*, pp. 173–179.

C. Sanjay, M.L. Neema and C.W. Chin, (2005). Modeling of tool wear in drilling by statistical analysis and artificial neural network, *Journal of Materials Processing Technology*, 170, pp. 494–500

E. Kai and M. Katsumi, (2002). Micro-drilling of monocrystalline silicon using a cutting tool, *Journal of the International Societies for Precision Engineering and Nanotechnology*, 26, pp. 263–268

F.H. Jung and D.L Psang, (2002). Mathematical model of multiflute drill point, *International Journal of Machine Tools & Manufacture*, 42, pp. 1181–1193

G..L. Hak, (2004). Tool Life Model for Abrasive Wet Micro-Drilling of Ceramics Green Bodies, Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology, 44(1), pp. 839-846.

H. Hocheng and C.C. Tsao, (2006). Effects of special drill bits on drilling-induced delamination of composite materials, *International Journal of Machine Tools & Manufacture*, 46, pp. 1403–1416

H. Nakagawa, K. Ogawa, A. Kihara and T. Hirogaki, (2007). Improvement of micro-drilled hole quality for printed wiring boards, *Journal of Materials Processing Technology*, 191, pp. 293–296

K. F. Ehmann and H.C. Chyan, (1997). Development of Curved Helical Micro Drill Point Technology for Micro-Hole Drilling, PhD Thesis. Northwestern University, Department of Mechanical Engineering, Evanston, USA.

M. Gerard and C. Francis, (1999). Quantitative measurement of the hardness profile on carbo-nitriding steel by the hole drilling method, *Measurement*, 25, pp. 291–298

R. Mauri and S. Matti, (1995). Tool wear and failure in the drilling of stainless steel, *Journal of Materials Processing Technology*, 52, pp. 35 - 43

S. Arula, L. Vijayaraghavana, S.K. Malhotrab and R. Krishnamurthya, (2006). The effect of vibratory drilling on hole quality in polymeric composites, *International Journal of Machine Tools & Manufacture*, 46, pp. 252–259

S.A. Jalali and W.J. Kolarik, (1991). Tool life and machinability models for drilling steels, *International Journal of Machine Tools & Manufacture*, 31 (3), pp. 273–282

S.C. Man, W.C. Dong and K.F. Ehmann, (1999). Identification and control for micro-drilling productivity enhancement, *International Journal of Machine Tools & Manufacture*, 39, pp. 1539–1561

T. Miyake, A. Yamamoto, K. Kitajima, Y. Yanaka and K. Takazawa, (1994). Syudy on mechanism of burr formation in drilling-deformation of material during burr formation *JSPE*-57-03, pp. 87-92

Y.C. Chen and Y.S. Liao (2003). Study on wear mechanisms in drilling of Inconel 718 superalloy, *Journal of Materials Processing Technology*, 140, pp. 269–273

Z. Yang, (1998). Study for Increasing Micro-Drilling Reliability by Vibrating Drilling, PhD Thesis. Reliability Engineering and System Safety, Jilin University of Technology, China.

Table 1. Data Collection for Brass

Tool Diameter [mm]	Spindle Speed, S [rpm]	Feed Rate, F [mm/min]	Time [s]	Material Removal Rate, (MRR) [mm/s]	Surface Roughness, *Ra* [µm]	Hole Diameter (min)
1	1000	1	17.59	0.785	2.318	1.012
		5	11.41	3.927	2.329	1.031
		10	10.59	7.854	2.358	1.053
	2000	1	18.01	1.571	2.315	1.113
		5	11.42	7.854	2.326	1.147
		10	10.58	15.708	2.341	1.173
	3000	1	18.03	2.356	2.279	1.210
		5	11.41	11.781	2.307	1.211
		10	10.57	23.562	2.336	1.232
0.9	1000	1	18.01	0.636	2.316	0.910
		5	11.4	3.181	2.327	0.914
		10	10.59	6.362	2.355	0.913
	2000	1	18.02	1.272	2.313	0.917
		5	11.42	6.362	2.322	0.919
		10	10.58	12.723	2.338	0.921
	3000	1	18.04	1.909	2.276	0.922
		5	11.41	9.543	2.304	0.923
		10	10.59	19.085	2.332	0.926
0.8	1000	1	18.11	0.503	2.314	0.811
		5	11.52	2.513	2.325	0.813
		10	11.1	5.027	2.353	0.817
	2000	1	18.13	1.005	2.311	0.822
		5	11.51	5.027	2.32	0.823
		10	11.1	10.053	2.336	0.831
	3000	1	18.13	1.508	2.274	0.832
		5	11.53	7.54	2.302	0.833
		10	11.1	15.08	2.331	0.836
0.7	1000	1	18.32	0.385	2.311	0.717
		5	12.11	1.925	2.322	0.718
		10	11.3	3.848	2.35	0.722
	2000	1	18.34	0.77	2.308	0.724
		5	12.09	3.848	2.317	0.725

	2000	10	11.29	7.697	2.333	0.728
		1	18.35	1.155	2.271	0.729
	3000	5	12.12	5.773	2.298	0.731
		10	11.28	11.545	2.327	0.733
		1	19.12	0.283	2.308	0.609
	1000	5	12.1	1.414	2.32	0.611
		10	11.27	2.827	2.346	0.613
		1	19.13	0.565	2.307	0.618
0.6	2000	5	12.11	2.827	2.315	0.622
		10	11.28	5.655	2.33	0.633
		1	19.13	0.848	2.267	0.635
	3000	5	12.12	4.241	2.295	0.637
		10	11.28	8.482	2.324	0.638
		1	19.15	0.196	2.305	0.511
	1000	5	12.09	0.982	2.318	0.514
		10	TB	TB	TB	TB
		1	19.13	0.393	2.304	0.517
0.5	2000	5	12.1	1.963	2.311	0.521
		10	TB	TB	TB	TB
		1	19.09	0.589	2.262	0.532
	3000	5	12.11	2.945	2.293	0.538
		10	TB	TB	TB	TB

TB = Tool Break

Machining time, MRR, surface roughness and dimensional accuracy obtained from the experiment using the calculation and measurement device.

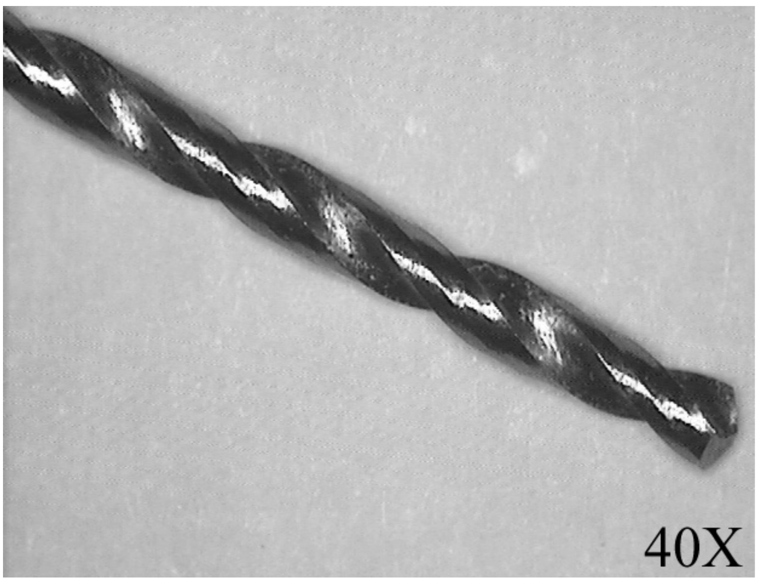


Figure 1. HSS drilling tool 1.0mm diameter under 40x by ICAMSCOPE

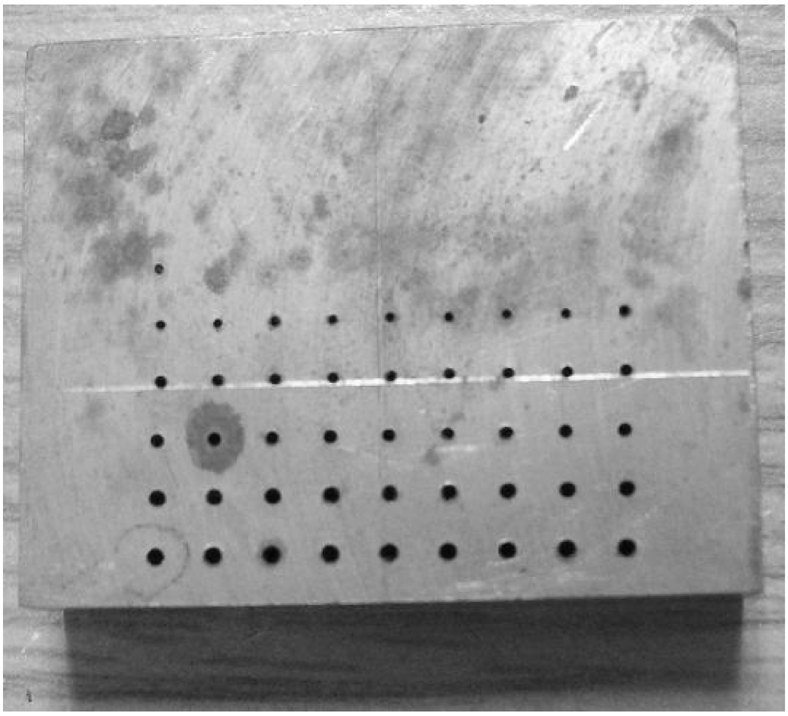


Figure 2. The drilled holes on brass

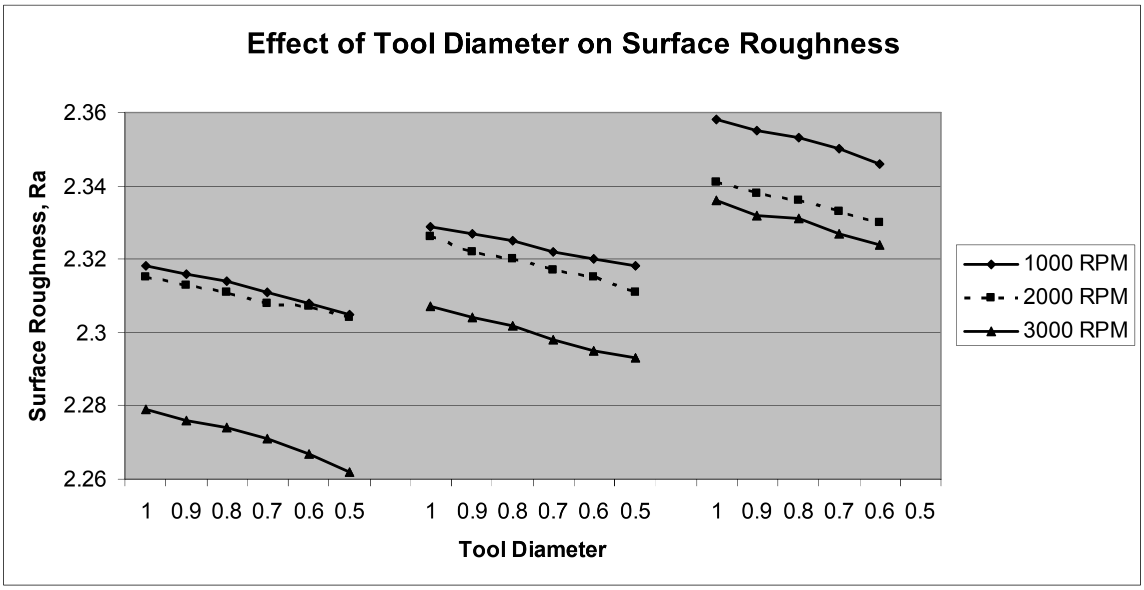
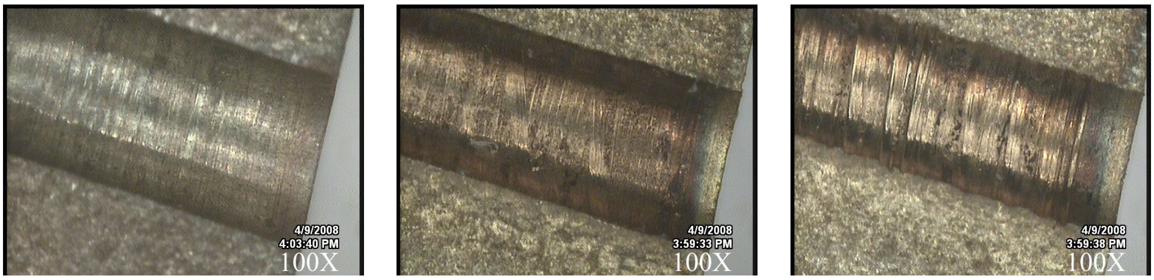


Figure 3. Effect of Tool Diameter on Surface Roughness



Feedrate =1 mm/min Feedrate = 5 mm/min Feedrate = 10 mm/min

Figure 4. Surface roughness of brass for different feedrate

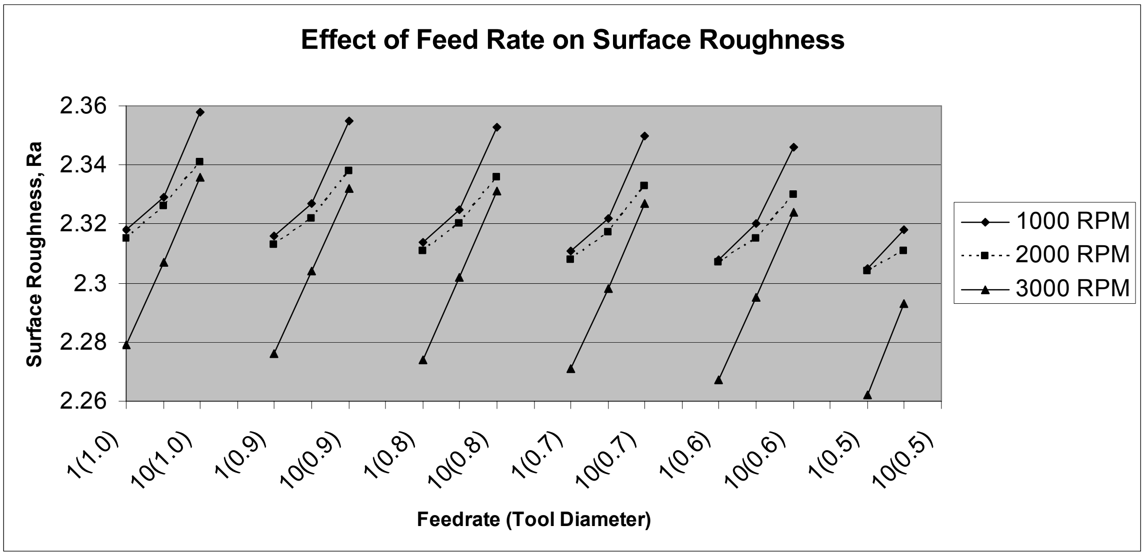


Figure 5. Effect of feed rate on surface roughness

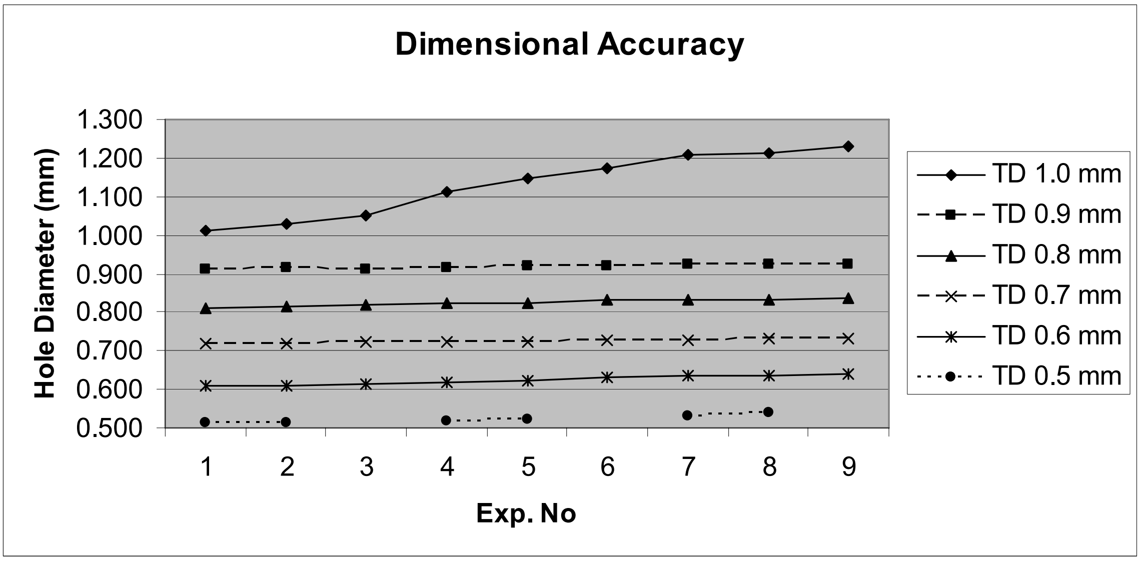


Figure 6. Dimensional accuracy for drilled holes

Figure 7. Tool wear occur at the edge of drilling tool

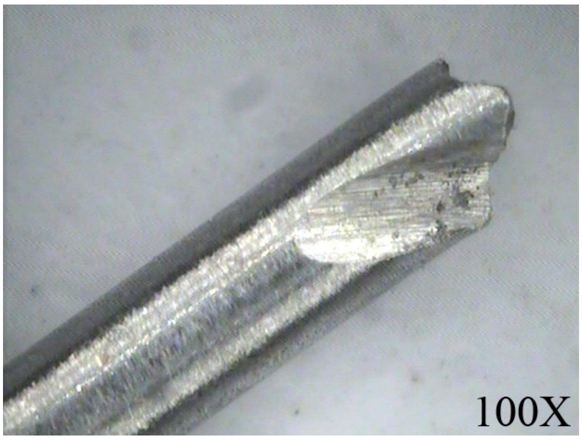


Figure 8. the breakages of drilling tool for 0.5 mm diameter

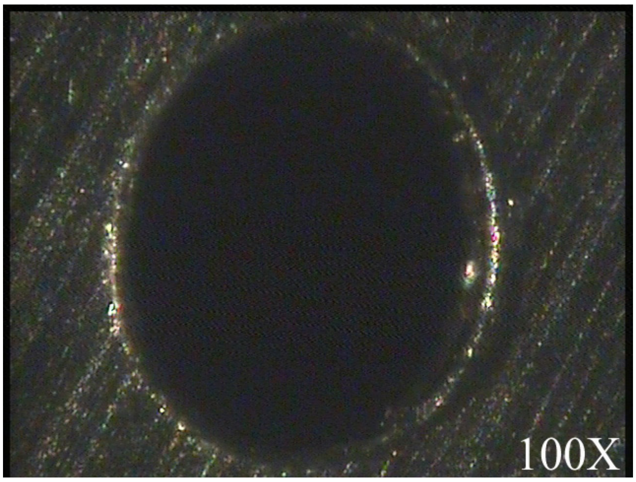


Figure 9. the on the edge and chip trapped inside the drilled hole

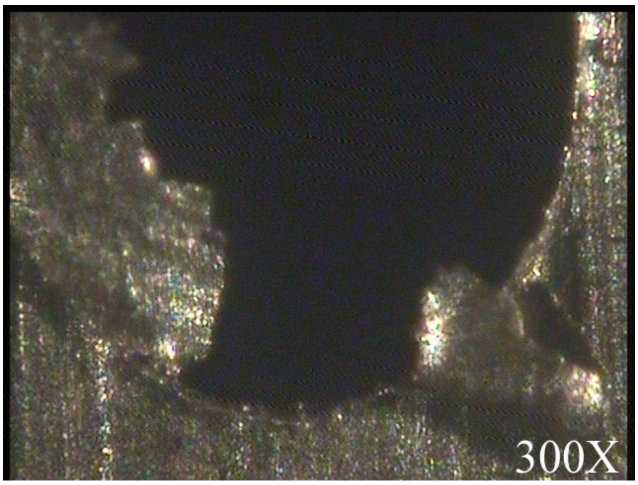


Figure 10. Burr with cap occur at the exit drill