American Journal of Mechanical Engineering, 2018, Vol. 6, No. 2, 54-60
Available online at http://pubs.sciepub.com/ajme/6/2/3

DOI:10.12691/ajme-6-2-3

Effects of Vegetable Oil Based Cutting Fluid in Machining Kevlar Composite Material

Md. Shoriat Ullah[1,*], Nikhil Ranjan Dhar[2,*]

[1]Department of Mechanical and Production Engineering,, Ahsanullah University of Science and Technology (AUST), Bangladesh
[2]Department of Industrial and Production Engineering, Bangladesh University of Engineering and Technology (BUET), Bangladesh
*Corresponding author: Shoriat.ipe09@gmail.com

Abstract Composite laminates are the first priority for many applications such as aerospace and aircraft structural components due to their superior properties. Composites offer a number of distinct advantages over more conventional engineering materials such as aluminium, steel etc. These benefits include higher specific strengths and stiffness's, superior corrosion resistance as well as improved fatigue properties. However, the benefits of its application are limited by the difficulty of machining due to its poor thermal conductivity. Excess cutting temperature affects the dimensional accuracy of the drilled hole and deteriorates its surface finish. As a result, acquiring a good surface finish and dimensional accuracy greatly dependent upon the control of the cutting parameters and appropriate use of cutting environments. The objective of the article is to evaluate the performance of vegetable oil-based cutting fluid on machining Kevlar composite. Furthermore, machining responses are compared with dry and wet cutting conditions to have appropriate machining environment. Drilled holes were evaluated based on surface roughness and dimensional accuracy. Apart from machining parameters, tool wear and chips formations also have been observed on given different machining conditions. Experimental investigation revealed that Vegetable based cutting fluid is better for surface roughness where machining accuracy deteriorate. Furthermore, tool wear and chips formation also improved significantly on vegetable based cutting fluid.

Keywords: *composite, drilling, vegetable oil, surface roughness*

Cite This Article: Md. Shoriat Ullah, and Nikhil Ranjan Dhar, "Effects of Vegetable Oil Based Cutting Fluid in Machining Kevlar Composite Material." *American Journal of Mechanical Engineering*, vol. 6, no. 2 (2018): 54-60. doi: 10.12691/ajme-6-2-3.

1. Introduction

Composites materials are used for their unusual combination of properties that cannot be met by the conventional metal alloys, ceramics, and polymeric materials. Composite materials are extensively used because of their higher strength to weight ratios and when compared to conventional metals and offer new opportunities for design. During machining, defects are formed because of low heat conductivity of workpiece and tools wear. The choice of the specific process depends upon following factors such as the type of machining process, part geometry and size, surface finish, and dimensional accuracy requirement, cutting tools and types and available coolants for heat etc. According to the article of Koplev, throughout the machining of the composite material a major proportion of the load exerted on the available fibers. Gaitonde, V. added that these loaded fiber's serve to impair uniform plastic deformation. The result is material removal by a series of fractures aided by the brittle nature of the matrix. Because of this, any machining without care might lead to delamination, burning, fiber pull-out, uncut fiber's, high surface roughness and lack of dimensional stability [1,2]. A.R. Abu Talib et al. [3] studied the effects of compressive and tensile load on Kevlar laminates and found that the (0°, 90°) orientation angle of fiber is stronger than the (+45°, -45°) orientation angle of fiber for all panels, which significantly affects the strength and stiffness of the composites. In addition, he also added that the failure occurred in all panels of Kevlar under compression load compared with tensile loading [4]. S. Abrate and D.A. Walton investigated and presented a review of traditional machining methods and suggested, in order to minimize the amount of heat generated and avoid thermal damage to the part, the proper tool geometry and operating conditions must be adopted. Because of the abrasive nature of the reinforcing fibres, carbide or diamond impregnated tools are satisfactory [5]. Drilling is the most common composite machining operation that can be applied to composite materials using appropriate tool design and operating conditions. Taskesen, A. stated that dimensional accuracy of drilling holes are negatively affected by the tool wear and has very less depends on cutting speed [4]. As drilling progresses, the tool is in contact with the side over an increasing area so that frictional forces at the interface create increasingly higher resistant torque. The higher amount of frictional force creates an excessive amount of heat which is caused of both damages in the tool and dimensional inaccuracy [6].

Eyup Bagci and Babur Ozcelik investigated twist drill bit during machining and observed that the temperature increases with drilling depth for same speeds and feed rates. But temperature values decrease on the twist drill bit with increase in feed rate for the same spindle speed and drilling depth values [7]. The principal drawbacks are related to surface delamination, fiber/resin pullout and excessive roughness of the hole wall. H. Ho-Cheng and C. K. H. Dharan investigated delamination and suggested that the larger the feed force, the more serious is the damage and a rapid increase in feed rate at the end of drilling will cause cracking around the exit edge of the hole [8]. Furthermore, he also studied drill bits to assess its involvement in this regard and found that twist drill bits are much more engaged in delamination during machining compare to other drill bits such as core, stick drill, saw drill and step drill bits because of shorter cycle time [9]. Machined surface quality is often characterized by morphology and integrity of the surface, and both of them depend on process and workpiece characteristics such as cutting speed, feed rate, fiber type and content, fire orientation, and matrix type and content and other machining parameters as stated by Ramulu et al. [10]. Another empirical study done by Liu et al. and they stated that the use of low feed rate and high cutting speed favour the minimum drilling-induced delamination and extend tool life [11]. Cutting fluids plays the major role to bring all the elements within acceptable limits by reducing the temperature of cutting zone.

According to Pei Yan et al. experimental studies, they found that in the cutting process, the material properties, geometric characteristics, and the corrosion resistance of the machined surface were significantly affected by different types of cutting fluids [12]. Cassin and Boothroyd stated that the use of proper cutting fluids minimizes or reduces burr formation and improve machining process [13]. Also, Dhar et al. states that without cooling and lubrication, the chip sticks to the tool and breaks it in a very short cutting time. It reduces cutting zone temperature either by removing heat as coolant or reducing the heat generation as the lubricant [14].

The main concern of this research is to eliminate the heat from investigated composite material by changing surrounding environments such as dry, cutting fluid and vegetable oil. In order to overcome these difficulties, it is necessary to asses cutting conditions to have an appropriate machining environment in a specified machining setup.

2. Experimental Investigation

2.1. Material

In this research, the experiment was limited to the drilling process of Kevlar composite laminated material. MR Piggott and B. Harris investigated the compression behaviour of aramid fibres and they found that Kevlar composites are much weaker in compression [15]. A combination of Glass fibres and Kevlar-49 fibres are used as hybrid composites using the lamination methods. Specifically, during the fabrication of material, 12 layers of Kevlar woven fabrics which are containing 300 GSM (Grams per square meter) and 13 layers is used as Glass fibres which is contain 250 GSM was used. Ply orientation was maintained at random. Kevlar woven fabrics layers are compressed with glass fibres material with the help of epoxy which is the prime matrix to form composite block material. The epoxy resin is used as a single matrix to combine both Kevlar and glass fibres. J. Kalantar and L.T. Drzal suggested that Aramid and Epoxy chemical interactions are strong enough to result in improved thermodynamic conductivity among the fiber's [16].

2.2. Machine Tool Setup, Tooling and Procedure

The experiment was conducted by Titanium coated high-speed steel (HSS) twist drill bits of diameter 8 mm. There were three Titanium coated HSS twist drill bits dedicated for three different machining conditions. The experiment was emphasized on conditions and its effects on machining parameters. The objective of the experiment was to quantify the ideal machining condition for composite material in the form of drilling. Therefore, we have used three dissimilar machining conditions to evaluate the proper one. One of them was a dry condition where natural coolant (air) was used. Another one was wet where traditional cutting fluid (VG 68) were used as a coolant and ratio of oil: water was 9:1. Lastly, vegetable oil (olive oil) was used as coolant.

The work piece was placed on the table of the drilling machine and clamped very rigidly with the help of vise. The experiment was started in dry environmental condition. The feed rate was 0.16 mm/rev and cutting speed was 25.13 m/min and the revolutions per minute (RPM) was 1000 and those cutting parameters were constant for the first 24 holes in a given cutting condition. The photographic view of experimental investigation is given in Figure 1.

(a) Dry condition (b) Cutting fluid (c) Vegetable oil (Olive oil)

Figure 1. The photographic view of experimental investigation

Table 1. Summary of the experiment

Machine Tool		Radial Drill Machine; Model: Z3032 X 10/1
Work Material	Fiber	12 layers Kevlar woven fabrics (300 GSM)
		13 layers Glass fiber (250 GSM)
	Matrix	Epoxy
Cutting Tool		Titanium coated HSS drill bits (Ø = 8mm)
Cutting fluid		Cutting fluid (VG-68)
		Vegetable Oil (Olive oil)
Cutting Parameters		
	Cutting velocity, V_c	25.13 m/min
	Feed rate, S_o	0.16 mm/rev
	Depth of cut, t	34.325mm
	RPM	1000
Environment		
		Dry
		Wet (Cutting fluid)
		Vegetable oil (olive oil)
Flow rate		0.01135 m^3/sec.

Subsequently, vegetable oil-based cutting fluid such as olive oil was used for next sets of machining. Vegetable oils consist of triacylglyceride (triglycerides) which are glycerol molecules with three long chain fatty acids attached at the hydroxyl groups via ester linkages. Long polar fatty acid chains provide high strength lubricant films. The vegetable oil used to reduce friction between tool and material during machining. So, it acts as better lubricant and coolant than dry condition machining. The cutting parameters remains the same as that of dry condition. Before applying a continuous flow of olive oil, measuring the flow rate of olive oil and that was 0.01135 m^3/sec. Finally, the wet condition was used to machining last set of holes. Cutting parameters remained constant as used in preceding machining conditions. The same continuous fluid flow rate was applied and that was 0.01135 m^3/sec. The following Table 1 shows the summary of the experiment where machining parameters are mentioned.

3. Results and Discussion

Typical drilled hole's configurations using three different tools and under three different conditions are shown in Figure 2. Photographic view of drilled holes is shown in Figure 2 for each condition by same machining parameters. Despite maintaining same machining parameters, variation in the hole diameter and roundness has been observed. Holes were measured by precision digital Vernier Callipers having least count 0.01 mm. At least, 8 measurements were taken at different positions for one hole to have average diameter. It helps to distinguish and identify a slight change in measurement. Mostly entrance delamination has been produced with the HSS drill bit during machining under dry condition rather than cutting fluid and vegetable oil-based machining.

Table 2 shows the maximum, minimum and average diameter of entry and exit of the drills at three different conditions such as dry, wet (cutting fluid) and vegetable oil (olive oil) based drilling operation.

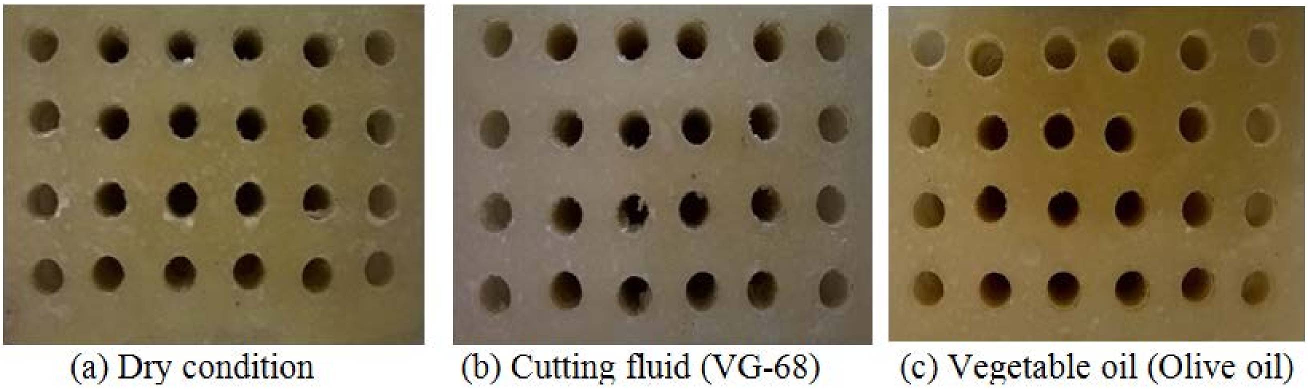


Figure 2. Photographic view of the drilled holes under different machining conditions

Table 2. The maximum, minimum and average diameter of holes at drill entry and exit under three different condition

Lubrication system	Diameter of the hole at drill entry			Diameter of the hole at drill exit.		
	$d_{maximun}$ (mm)	$d_{minimum}$ (mm)	$d_{average}$ (mm)	$d_{maximun}$ (mm)	$d_{minimum}$ (mm)	$d_{average}$ (mm)
Dry	8	7.68	7.84	8.11	7.75	7.93
Cutting fluid	7.95	7.75	7.85	7.94	7.69	7.815
Vegetable oil (Olive oil)	8.06	7.76	7.91	7.97	7.68	7.825

Variation of roundness of the drilled holes close to drill exit with respect to no. of holes at speed 25.13 m/min and feed rate 0.16 m/rev under three conditions such as dry, wet (cutting fluid) and vegetable oil (olive oil) are shown in Figure 3. According to the figure it is difficult to find any pattern but on average cutting fluid machining condition shows better roundness compare to others,

The maximum, minimum and the average value of diameter at entry and exit of the drilled holes under three different conditions are found in graphical representation. Results obtained is shown in Figure 4. The average and deviations of roundness are easily evident from the given graph.

3.1. Surface Topography

Surface roughness parameter (R_a) is rated as the arithmetic average deviation of the surface valleys and peaks expressed in μm. Drilled holes were measured to identify and investigate holes' roughness. The cutting speed and feed have insignificant effect on surface roughness but on the other hand drill diameter combined with feed have significant role on surface topology found by El-Sonbaty et al. [17]. Table 3 shows measured surface roughness of drilled holes during machining at speed 25.13 m/min and feed rate 0.16 m/rev. by Titanium coated HSS twist drill bit under different conditions such as dry condition, Cutting fluid and vegetable oil.

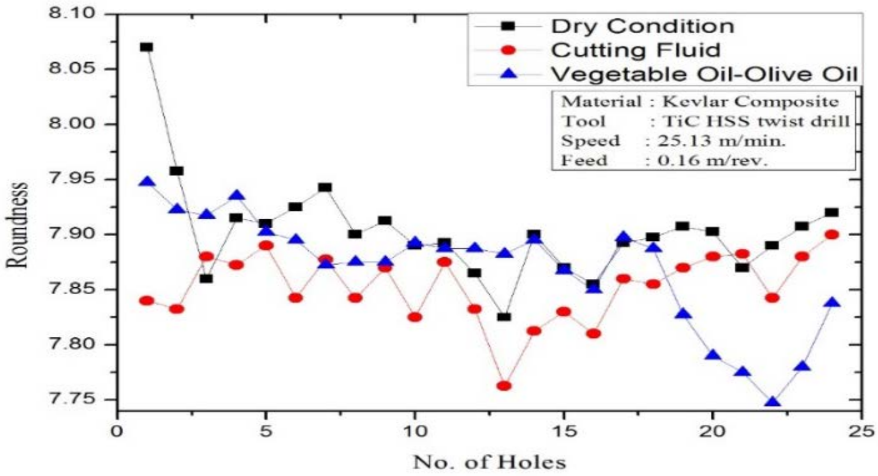
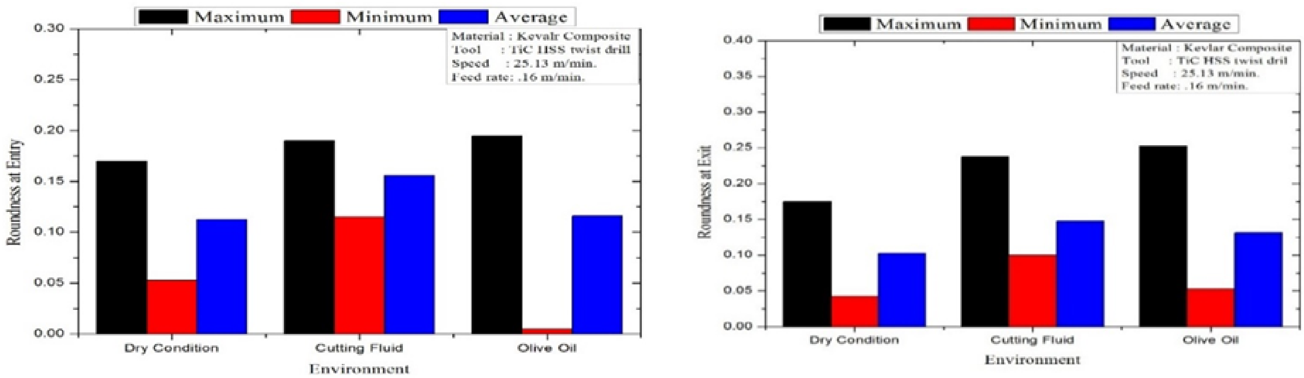


Figure 3. Roundness vs. No. of holes close to drill exit



(a) Roundness at drill entry (b) Roundness at drill exit

Figure 4. The maximum, minimum and the average diameter at drill entry (a) and drill exit (b) under different conditions

Table 3. Surface roughness of drilled holes under different machining conditions

No. of Holes	Roughness (µm)			No. of Holes	Roughness (µm)		
	Dry	Cutting fluid	Vegetable Oil (Olive)		Dry	Cutting fluid	Vegetable Oil (Olive)
01	3.36	2.46	1.68	13	3.56	3.16	2.12
02	5.08	3.54	2.58	14	4.82	2.32	3.14
03	5.00	4.36	2.32	15	4.42	2.04	2.96
04	5.64	3.82	3.10	16	4.18	2.14	1.34
05	4.04	2.94	2.48	17	3.92	3.44	1.48
06	4.04	3.96	2.32	18	3.32	3.26	2.10
07	3.84	3.16	2.40	19	2.68	2.66	2.18
08	3.56	2.96	2.52	20	3.62	1.42	2.20
09	4.40	2.68	2.38	21	5.20	4.06	2.42
10	5.74	3.34	2.58	22	3.32	3.28	2.32
11	4.72	3.24	2.06	23	4.08	3.50	1.48
12	4.10	2.50	2.08	24	3.88	3.84	2.08

From the above Table 3, it can be concluded that the average roughness of drilled hole under dry, cutting fluid and vegetable oil is 4.188 µm, 3.087 µm and 2.263 µm respectively. These values easily help to reach in a verdict that vegetable oil is favorable for surface topology from others traditional machining conditions.

It is evident from the Figure 5 that the average surface roughness is in better place under vegetable oil rather than dry and cutting fluid in terms of average values. It shows hole roughness vs. No. of holes and the maximum, minimum and average values of roughness under different machining conditions.

3.2. Tool Wear

Tool wear is inevitable when machining composite material as heat is generated due to friction between chips and cutting edge. Dedicated Titanium coated HSS twist drill bit was used during machining of the composite material for each different machining conditions. Wear test was carried out by Zitoune et al. and found that the quality of holes machined with coated tool is better when compared to uncoated tool [18]. Figure 6 shows the tool wear for the dry, wet and vegetable oil condition.

According to Figure 6 tool wear at dry condition is relatively less compared to that of cutting fluid condition. The tool tip has built up edge during machining under dry condition which has caused for chips deformation and less wear. Overall minimum tool wear was observed for the vegetable oil condition.

3.3. Chips Formation

Proper machining responses especially surface roughness, dimensional accuracy and tool wear always reflected by the chip formation. As chips are subjected to the heat and force generated by machining, chip has a significant role to make a conclusion about the machining performances. Investigation conducted by E. Brinksmeierl and R. Janssen about the suitable cutting environments and suggested minimum quantity lubricant (MQL) with internal supply in case of multi-layer composite drilling is better option rather other traditional cutting conditions [19]. Effect of diameter of drill and feed rate seem to have significant role on chip breakability because of the increase in cross sectional area of chip whereas effect of spindle speed seems to be insignificant. In the drilling operation, small well broken chips are desirable as suggested by Redouane Zitoune et al [20]. During the investigation of chips, uniformity has been maintained to assess the chips from the equal perspective as selection of chips are picked from 1st, 12th and 24th no. of holes by each of machining conditions. Figure 7 shows the photographic view of chips of above mentioned holes generated from respective machining conditions. The number of holes were the same for every machining conditions to understand the pattern of chip formation.

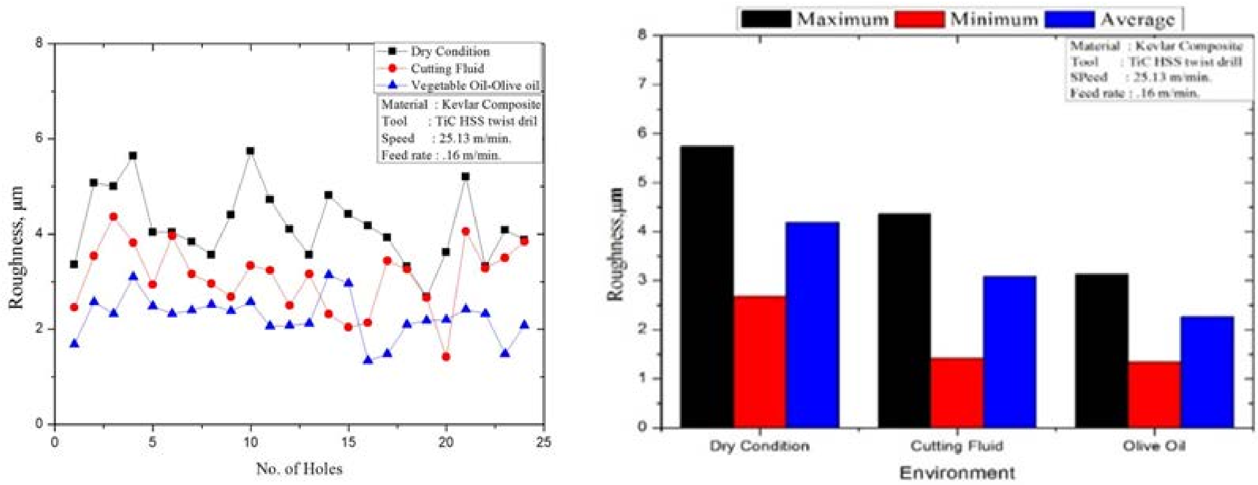
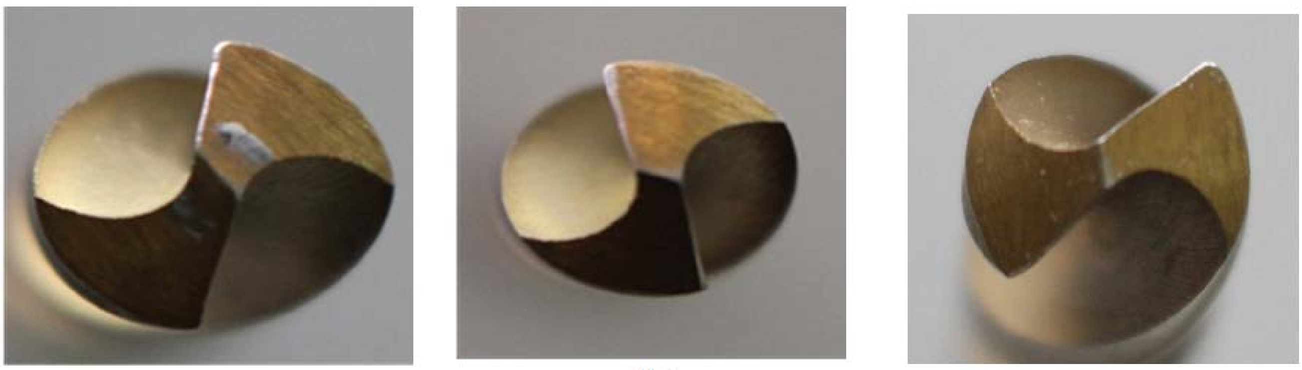


Figure 5. (a) Variation of holes' roughness (µm) under different conditions. (b) The maximum, minimum and the average value of roughness under different conditions



(a) (b) (c)

Figure 6. Photographic view of tool wear; (a) Dry condition (b) Cutting fluid (c) Vegetable oil (Olive oil)

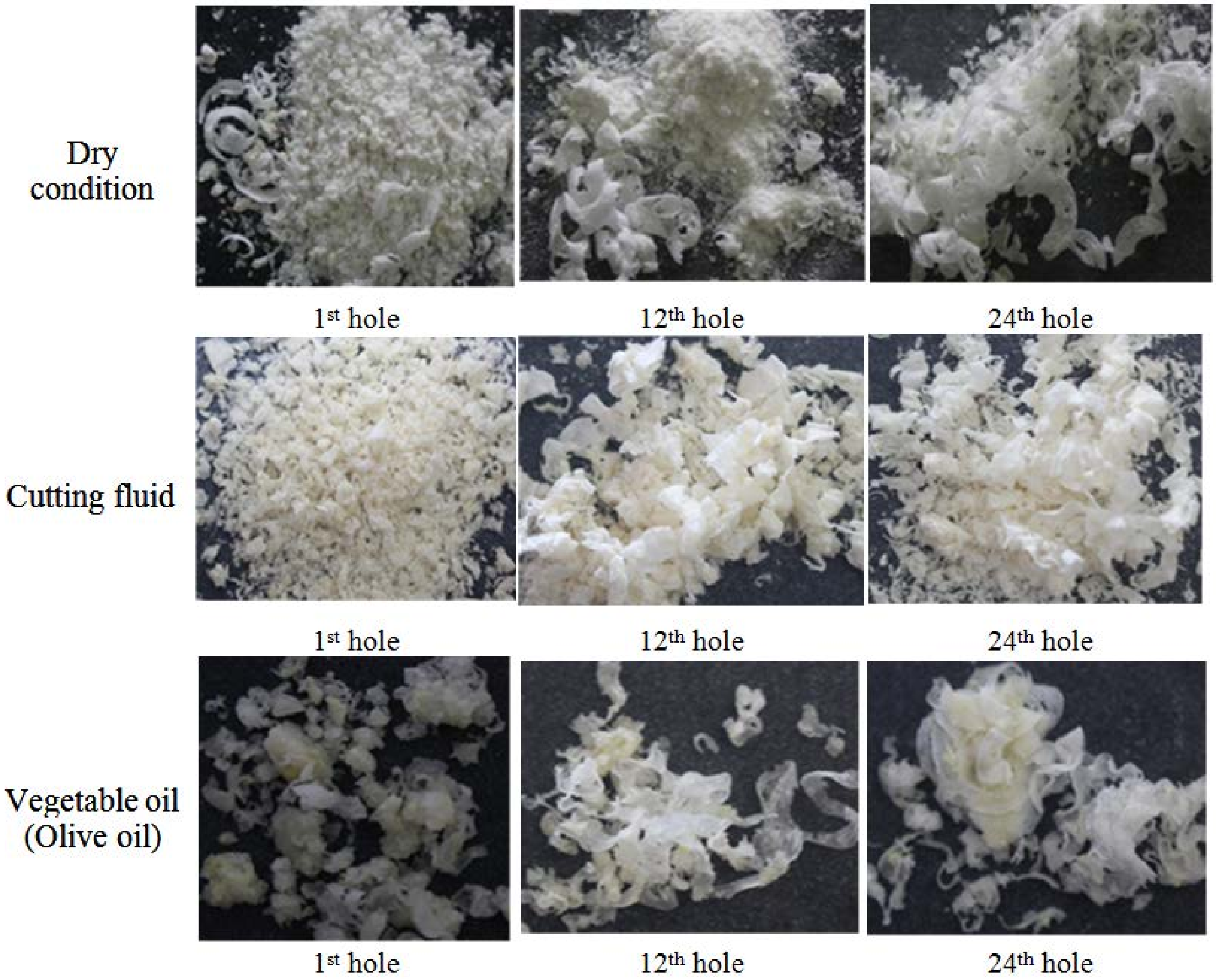


Figure 7. Photographic view of chips

It is evident from the above presented graphical view that initial chips are discontinuous and powder shaped (dry). On the contrary generated chips from the last hole of corresponding machining environment is continuous and ribbon shaped (vegetable oil). Though dry machining creates powder shaped chips but also responsible for the most rougher surface finish. Conversely, where vegetable oil creates ribbon shaped chips but also creates better surface finished hole.

3.4. Conclusion

The aim of this experiment is to find out the effect of vegetable oil-based cutting fluid in machining Kevlar and glass fiber composite. Based on the experimental results and factual observations the following conclusions can be drawn-

1. From abovementioned assessment of different traditional cutting environments, it can be concluded that vegetable oil improves the tool life rather than dry or cutting fluid. Moreover, vegetable oil helps to reduce the temperature from the cutting zone and provides more lubrication to the chip tool interface.
2. Excessive heat creates built-up edge during machining under dry condition. As a result, this phenomenon effects the hole surface quality and chip size. This effect can be seen as powder shaped chips formed under dry condition and average value of surface finish was 4.188 µm.
3. In case of chip formation, it is apparent from above figure (Figure 7) that beginning of each of the drilling by their corresponding cutting environments and pristine drill bit initially creates discontinuous (vegetable) and powder shaped (dry condition and cutting fluid) chips but as machining continues with the same tool and condition, chips are tending to be spiral and continuous shape. It has been observed from Table 3 that good surface finish is obtained by applying cutting fluids rather than the dry conditions as the average roughness is 4.188 µm, 3.087 µm respectively. On the contrary, the vegetable oil (olive oil) shows the best surface finish because of good properties and forms gummy deposit which may cause machine slide to become sticky or clog the circulating system. As a result, surface roughness during machining under vegetable oil is better than other conventional machining conditions.
4. Roundness deviation is better under dry condition for both the entry and exit of the holes due to discontinuous types of chips. Such chips can be removed easily within the spiral channel of the drill bit. Moreover, the shrinkage behavior of fiber

composite also contributed in a way that the vegetable oil and wet conditions were failed to create better dimensional accuracy.

The above experimental investigation and further analysis revealed that machining environments exerts crucial role on average surface roughness, dimensional accuracy and tool life. Moreover, vegetable oil is the better choice if surface roughness and tool life is the main concern. On the contrast, dimensional accuracy can be achieved by the dry condition during machining composite materials.

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