Reason- A Technical Journal
ISSN 2277-1654
Volume XVII 2018

AN EXPERIMENTAL STUDY OF GRINDING PERFORMANCES OF A MILD STEEL UNDER DIFFERENT ENVIRONMENTAL CONDITIONS USING VARIOUS TYPES OF NOZZLES

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Paper received on: January 12, 2020, accepted after revision on: March 25, 2020
DOI:10.21843/reas/2018/48-56/195549

Abstract: Grinding is a mechanical metal removal process used in manufacturing industries. In this process, the material is removed from a work-piece material by an abrasive wheel. This process gives better surface finish and close tolerance. Grinding process removes material by shearing, ploughing, rubbing and brittle fracture with high-speed and a high input of energy per unit volume. The coolant or grinding fluid is used to reduce the temperature in grinding zone and also it is used as a lubricant into grinding zone. In present work, a five port multi-nozzle system has been developed and performance of this nozzle has been compared with flood type copper cooling nozzle under different environmental conditions. Two parameters (chip characteristics, surface roughness) of grinding are considered to find the suitable process for grinding of a mild steel specimen. From this experimental investigation, it can be observed that in wet condition, five port multi-nozzle system provides better surface finish as well as it is more economical.

Keywords: Five port multi-nozzle, surface roughness, depth of cut, grinding, chip, dry test.

1. INTRODUCTION

Grinding is a process of abrasive machining [1]. It is a multi-teeth operation in which high-speed rotating grinding wheel, made up of abrasive grains, acts like a cutting tool [1]. Grindability Index is sometimes used to describe the relative case of grinding and is comparable to machinability for single point cutting tool [2]. It deals with the forces and power required in grinding, wheel wear, stock removal rate and the surface finish produced [2]. A material is considered to have good grindability Index if the power, wheel wear and forces are low, while stock removal rate is high and produced surface finish is good [2].

Grinding wheel is made up of large number of abrasive particles called grains and they are held together by a bond material [3]. Cutting action of grinding wheel is similar to a milling cutter with exception that cutting edges of grinding wheel are irregular in nature [3]. High temperature (1000°C-1500°C) is generated in grinding due to irregular geometry of active grains, negative rake angle of cutting edges and large scale rubbing action [2]. Five characteristics of a cutting wheel are considered such as abrasive grain, grain size, wheel grade, grain spacing, and wheel bond type [2] to construct its specification.

Coolant delivery system is usually used in grinding operation because of the following reasons:

- Dressing frequency is reduced due to less loading with work material [4].
- Wearing of abrasive grains is reduced [3].
- It reduces thermal damage of the work piece material [3].
- It allows higher material removal rate [4].
- It promotes high wheel speed to alleviate burn [4].

In 1991, W.B. Rowe, M.N. Morgan and D.A. Allanson concluded that the performance of coherent-jet nozzle had been better than the other nozzle because it could concentrate the coolant into the grinding zone [5]. In 2006, G. Cai, X. Xu and R. Kang together did an experiment and expressed that during the grinding process, high specific energy is required and high temperature is produced in the grinding zone. It requires a new high efficiency cooling technology such as cryogenic mist jet impinging (CPMJI) cooling technology [6-8]. In 2008, B. Nishanth, S. Kumar, G. Praveen and A. K. Chattopadhyay did an experiment by using various types of coolants to reduce the temperature during grinding operation. They showed that the effect of a coolant provided a definite improvement in the grit life [9]. B. Mandal, S. Majumdar, S. Das and S. Banerjee investigated in 2011 and concluded that effectiveness of the grinding fluid could be improved to some extent by using rexine leather pasted wheel, scraper board, z-z method, or by applying fluid in the form of jet or mist [10]. After doing an experiment in 2011, B. Mandal, R. Singh, S. Das, and S. Banerjee had shown that multi-nozzle fluid delivery system had been much effective in grinding because the fluid flow through grinding zone could be more with the increase in number of fluid delivery nozzles [11]. B. Mandal did an experiment using a pneumatic barrier set up by which more fluid could pass through the grinding zone, and the temperature of grinding zone could be controlled effectively. A multi-nozzle system was also developed [12] by them for delivering grinding fluid which could reduce wastage of fluid applied.

2. EXPERIMENTAL SETUP

The experiment has been performed on a surface grinder with the grinding wheel made up of aluminum oxide (Al2O3) as shown in Fig. 1. The velocity of grinding wheel has been used around 30 m/s throughout the experiment and table speed has been maintained around 0.25m/s. The specifications of surface grinder are shown in Table 1. The specification of cutting fluid is given in Table 2 and mild steel is used as a working specimen. Mild steel used consists of 0.16% C, 0.07% Al, 0.168% Si, 0.18% Mn, 0.025% P, 0.09% Cu and rest amount of Fe [1].

Fig. 1: Surface Grinder

Table 1: Specification of Surface Grinder

Working surface area of grinding machine	225 x 500 mm
Max. Magnetic Table Travel L x B	250 x 525 mm
Max. Grd. Height Under Wheel	240mm
Vertical Feed Graduation	0.01 mm
Cross Feed Graduation	0.05 mm
Elevator movement with MICROFEED	0.001 mm
Spindle Speed	2800 RPM
Grinding wheel (Dia. x Bore x Width)	178 x 31.75 x 12.7
Electric Motor	1.0 HP, 3PHASE

Table 2: Characterization of the cutting fluid used [9]

Cutting Fluid	pH (Emulsion 8%)	Density (g/ml)	Viscosity at 40°C (mm^2/sec)	Viscosity at 40°C (mm^2/sec) (of 8% Emulsion)	Flash Point (°C)	Refractive Index
CMCF	9.40	0.906	29	1.4	175	1.482

Mitutoyo Surface Roughness Tester (Fig. 4) has been used to measure surface roughness of the work-piece material. It provides surface roughness profile of the ground surface and the values of average surface roughness height (Ra), Root mean square roughness (Rq), and average maximum height of the profile (Rz) of the ground surface.

The five port multi-nozzle system has been made up of 1 mm aluminium sheet for the experimental purpose as shown in Fig. 2. Outlet diameter of each nozzle (5 nozzles) is 3.74 mm. For another wet test, flood type copper cooling nozzle (made up of copper pipe) has been used as shown in Fig. 3. Outlet diameter of flood type copper cooling nozzle is 9.47 mm.

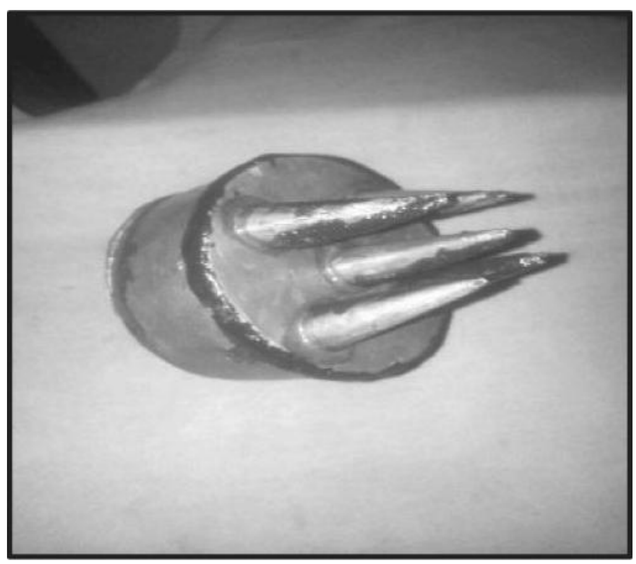


Fig. 2: Five port multi-nozzle

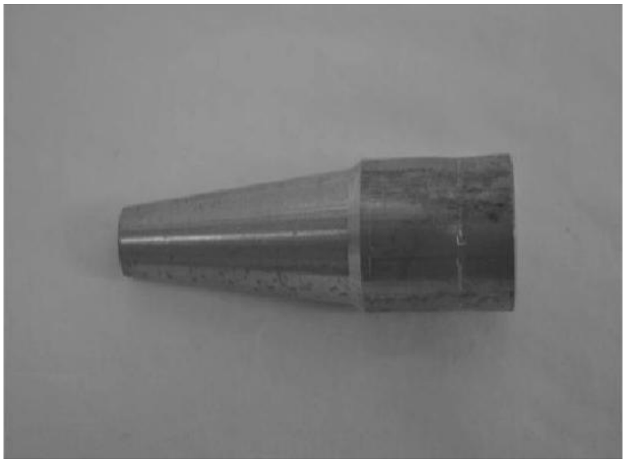
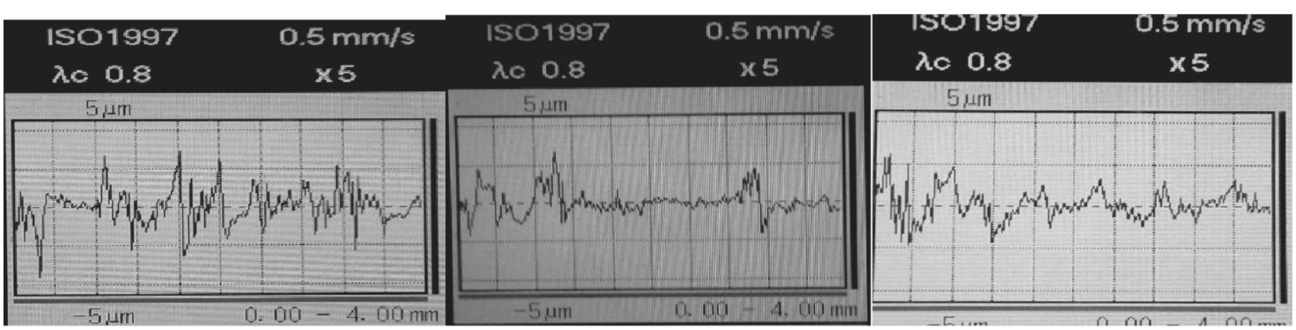


Fig. 3: Flood type copper cooling nozzle

Fig. 4: Mitutoyo Surface Roughness Tester (Talysurf)

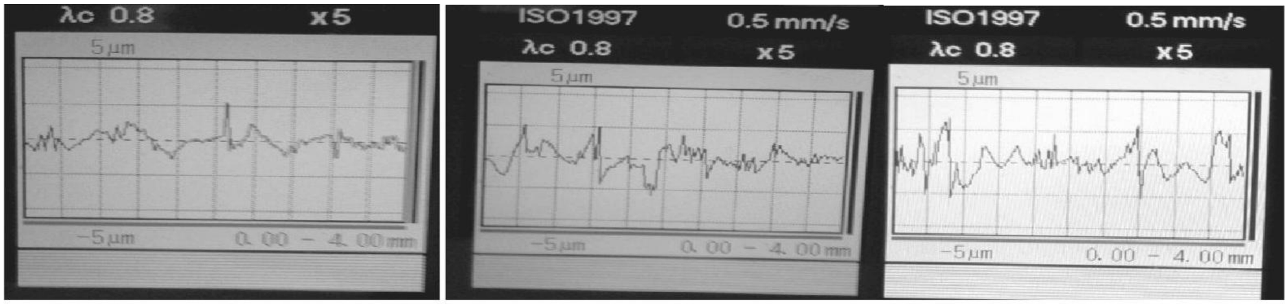
3. EXPERIMENTAL METHODOLOGY

The grinding operation has been done under three different conditions with three different depth of cut such as 10 µm, 20 µm and 30 µm. Three different conditions are Dry, Wet through five port multi-nozzle and wet through flood type copper cooling nozzle. For performing surface roughness test, the standard detector of Talysurf has been placed on a ground surface. Then the Talysurf has been turned on and the standard detector of talysurf started moving in forward and backward direction for measuring surface roughness. Fig. 5 shows the surface roughness profile of ground surface for a dry test. Similar surface roughness profiles are shown in Fig. 6 and Fig. 7 for wet test through five port multi-nozzle and through flood type copper cooling nozzle respectively.



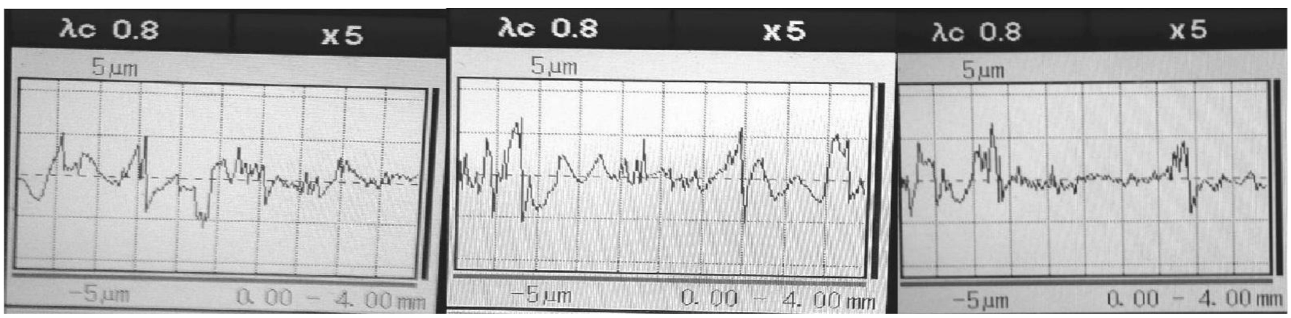
A B C

Fig. 5: Surface roughness profile for dry test after 10 passes at a depth of cut of (A) 10 µm, (B) 20 µm and (C) 30 µm.



A B C

Fig 6: Surface roughness profile for wet test through five port multi-nozzle system after 10 passes at a depth of cut of (A) 10 µm, (B) 20 µm and (C) 30 µm.



A **B** **C**

Fig. 7: Surface roughness graph for wet test through flood type copper cooling nozzle after 10 passes at a depth of cut of (A) 10 µm, (B) 20 µm and (C) 30 µm.

Besides displaying surface roughness profiles, Mitutoyo Surface Roughness Tester provides Ra, Rq, Rz values of the ground surface as shown in Table 3-5. Values of Ra, Rq, Rz for dry test, wet test through five port multi-nozzle and wet test through flood type copper cooling nozzle have been given in Table 3, Table 4 and Table 5 respectively.

Table 3: Surface roughness values after dry Test

Depth of cut/pass (µm)	Ra (µm)	Rq (µm)	R_z (µm)
10	0.542	0.716	3.261
20	0.609	0.854	4.630
30	0.964	1.235	5.552

Table 4: Surface roughness values after wet test (through 5-port multi-nozzle)

Depth of cut/pass (µm)	Ra (µm)	Rq (µm)	R_z (µm)
10	0.397	0.508	2.341
20	0.537	0.675	3.369
30	0.771	0.969	4.197

Table 5: Surface roughness values after wet test (through flood type copper cooling nozzle)

Depth of cut/pass (μm)	Ra (μm)	Rq (μm)	R_z (μm)
10	0.419	0.522	2.374
20	0.562	0.698	3.402
30	0.805	0.985	4.229

4. COMPARISON OF EXPERIMENTAL DATA AND OBSERVATION OF CHIP QUALITY

To get better surface finish, surface roughness of the ground surface should be decreased and it can be achieved by providing better coolant penetration into the grinding zone. So the surface roughness test has been performed at every condition to find which nozzle system provides better penetration of coolant into the grinding zone.

Fig. 8 shows the comparison of average roughness height (Ra) of ground surface under different conditions with various depths of cut. Fig. 9 shows the comparison of root mean square roughness (Rq) of ground surface among different conditions with various depth of cut. Fig. 10 shows the comparison of average maximum height of the profile (Rz) of ground surface under different conditions with various depth of cut. Results are compared to find the better grinding conditions among the given conditions.

Fig. 8, Fig. 9 and Fig. 10 clearly show that five port multi-nozzle system provides better environment for grinding operation than other two experimental conditions that may be because of better control of temperature during grinding.

Chips were collected and observed under tool maker's microscope with 20X zoom capacity as shown in Fig 11, Fig. 12 and Fig. 13. More spherical chips indicate high grinding temperature. So, the microscopic views of chips have been observed to find in which condition the lowest amount of spherical chips have been occurred that correspond to low grinding temperature. Advantages of generating lowest temperature in the grinding zone [3, 8] are:

- Reduction in working surface burns.
- Reduction of open and subsurface cracks.
- Reduction of tensile residual stress.
- Reduction of uncontrollable material removal rates.
- Reduction of oxidation and corrosion rates.

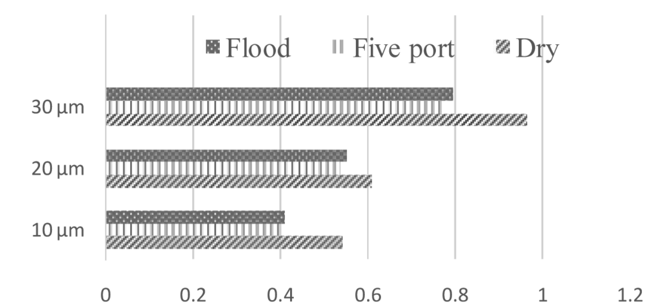


Fig 8: Comparison of Ra under different condition

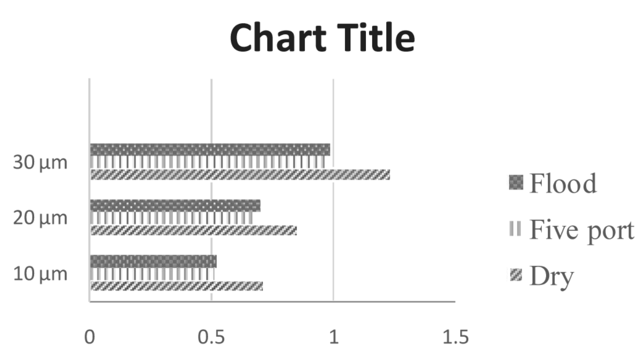


Fig 9: Comparison of Rq under different conditions

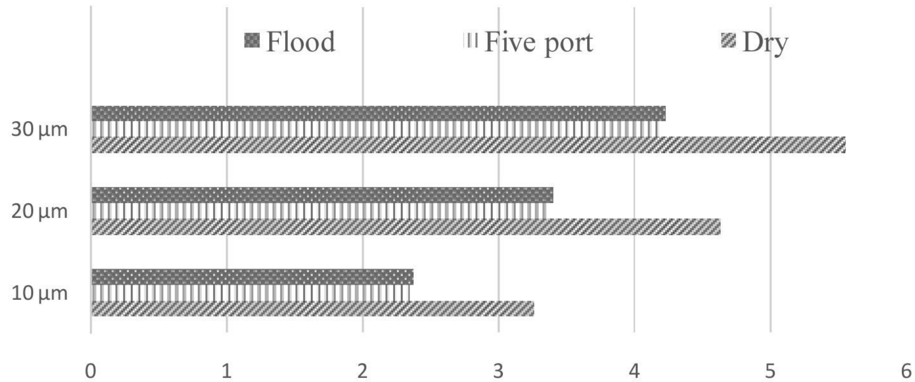


Fig 10: Comparison of Rz under different conditions

Fig. 11, Fig. 12 and Fig. 13 clearly show that five port multi-nozzle system provides less amount of spherical chips in all the conditions. Therefore, less temperature rise happens at the grinding zone when five port multi-nozzle system is used for delivering the coolant because five port multi-nozzle system provides better penetration of coolant into the grinding zone.

Flow rate of every nozzle is calculated in ltr/hr, to find more cost-effective nozzle system between five port multi-nozzle and flood type copper cooling nozzle.

- For high velocity five port multi-nozzle fluid delivery technique:

  Diameter of each nozzle (5 nozzles) = 3.74 mm.

  Area of the outlet of each nozzle = $\frac{22}{7}$ x 3.74^2 mm^2 = 43.961 mm^2

  Total area of outlets of five port multi-nozzle = 5 × 43.961 = 219.805 mm^2

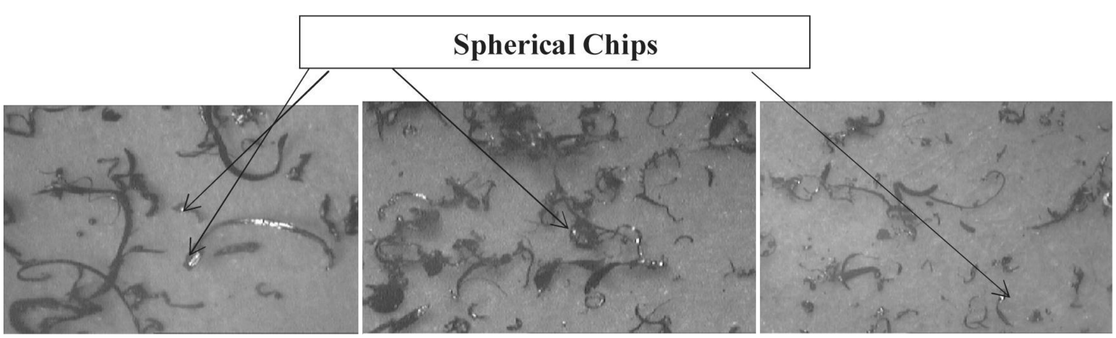
  Flow rate = 16 ltr/hr.

- Flood type fluid delivery technique through copper pipe:

  Diameter of copper pipe = 9.47 mm

  Area of the outlet of flood type nozzle = $\frac{22}{7}$ x 9.47^2 mm^2 = 281.854 mm^2

  Flow rate = 20.5 ltr/hr.



a b c

Fig. 11: Microscopic view of grinding chips after 10 passes with 10 µmin feed under (a) dry condition, (b) wet condition using five port multi-nozzle cooling system, (c) wet condition using flood type copper cooling system

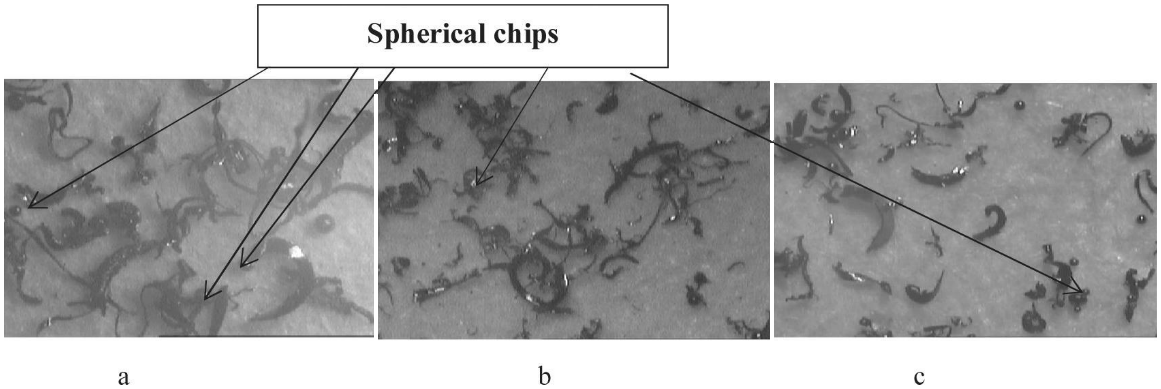


Fig. 12: Microscopic view of grinding chips after 10 passes with 20 µmin feed under (a) dry condition, (b) wet condition using five port multi-nozzle cooling system, (c) wet condition using flood type copper cooling system

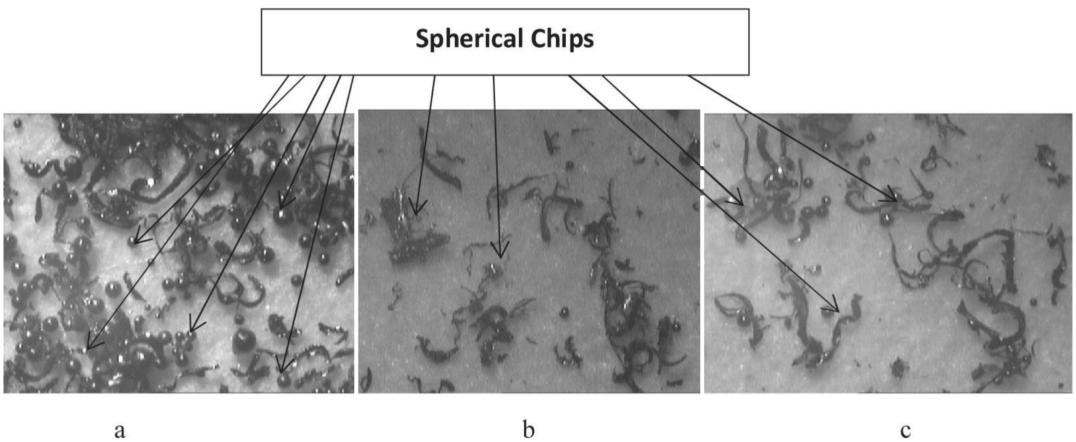


Fig. 13: Microscopic view of grinding chips after 10 passes with 30 µmin feed under (a) dry condition, (b) wet condition using five port multi-nozzle cooling system, (c) wet condition using flood type copper cooling system

5. CONCLUSION

From the above experimental observations, it can be concluded that

- All the parameters of surface roughness are quite high in case of dry grinding process. Again in case of wet grinding process, when five port multi-nozzle is used, the parameters of surface roughness are quite lower than the parameters of surface roughness of wet grinding using flood type copper cooling nozzle.
- In grinding, spherical chips are formed because of high temperature rise at the grinding zone. It can be stated that lesser amount of heat is generated at the grinding zone when wet test has been performed through five port multi-nozzle than other two processes. Again, flow rate of five port multi-nozzle is lower than the flood type copper cooling nozzle. So, more amount of coolant has been wasted in the case of flood type copper cooling nozzle system. Hence, five Port multi- nozzle system is more economical.

- Reason behind the better performance of five port multi-nozzle than flood type copper cooling nozzle may be that every port of five port multi-nozzles concentrates the coolant or lubricant into the grinding zone to provide better lubrication system and as a result, surface finishing gets better. Also, penetration of the coolant into grinding zone becomes more, by which the coolant takes much amount of heat from the grinding zone thereby reducing grinding zone temperature. Low grinding temperature may have resulted in controlling formation of open and subsurface cracks of the ground surface as well as wheel loading and favourable chip formation.

Acknowledgement: The present paper is based on the article presented in the National Conference on Trends and Advances in Mechanical Engineering (TAME-2019) held at Kalyani Govt. Engineering College, Kalyani on February 15-16 2019 and jointly organized by The Association of Engineers, India, Kalyani Govt. Engineering College, Kalyani and Global Institute of Management and Technology, Krishnagar as a part of the Centenary Celebration of the Association of Engineers, India.

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