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Improvement of Lubrication and Cooling in Grinding by Effective Controlling of Air Boundary

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Abstract: The presence of air around a rotating grinding wheel impedes the effective entry of coolant into grinding zone. Therefore, a proficient method is required to minimize this air boundary before the impingement of fluid-jet into the grinding zone. This paper is an experimental study for finding the better effective method of controlling the air boundary around the wheel. Further, two different techniques of suppressing the air barrier has been studied experimentally and statistically towards improving the cutting fluid action in grinding. Fuzzy models are developed to interpret the relationship between the variables and responses. Experiments are conducted on a horizontal surface grinding machine with the application of scraper board and pneumatic barrier separately behind the flood cooling nozzle. The surface roughness and other mechanical properties of these two methods and traditional flood cooling method are compared. The experimental results specified that the tangential force and the requirement of specific energy are reduced by maximum 25% and 20% respectively by the scraper board (SB) with the comparison to the pneumatic barrier (PnB) method for achieving the equivalent surface quality when tested by positioning them at 60° location from grinding zone. Hence, use of scraper board at close proximity to grinding zone is recommended.

Keywords: Scraper Board, Pneumatic Barrier, Grinding Forces, Surface Texture, ANOVA, Statistical Analysis

1. Introduction

In the process of grinding, improper entry of coolant into the grinding zone leads to the increase of surface roughness of the finished product, surface burn, residual stress, surface and subsurface crack, wheel loading, etc. [1-3]. Lubrication at the contact zone increases the process performances [4]. But it becomes increasingly difficult to feed fluid into the interface of the wheel and the workpiece due to the presence of a rotating air layer around the wheel by conventional flood nozzle [2, 5]. The pressure of the air layer around the grinding wheel becomes stronger with the increase of wheel speed [6]. The air barrier is even at low speed does not allow the entry of fluid properly through the contact area. Therefore, depletion of this re-circulating air from around the grinding zone may be helpful before impingement of fluid into the contact zone of the wheel and workpiece. The introduction of a scraper board can deflect this airstrip and reduces the effect of boundary air [6]. The pneumatic barrier has also been found to reduce the air barrier. The researchers have observed the optimum grindability at 43.5° polar angle and 33° swivel angle of pneumatic nozzle in their test [7, 8]. But the more useful method by which the suppression of this rotating air is possible more effectively is required to be examined so that the strategy of issuing fluid jet into the grinding zone can be made.

Guo and Malkin have experienced that only 5 to 30% of cutting fluid can enter into the contact region by conventional flood cooling due to the presence of the air layer around the grinding wheel [9]. As a result, attrition wear of grits occurs early and increases wheel wear. Mondal et al. have seen that the effect of the air boundary reduces by pasting rexine cloth on both side faces of grinding wheel [10]. The introduction of scraper board or pneumatic barrier along with the rexine pasted wheel can also reduce this air boundary layer [9]. Morgan et al. by CFD analysis have seen that the boundary air quickly reforms after a scraper plate [11]. Nearly 27% decreases in air layer pressure have been observed with the use of a scraper board maintained 75° away from measuring probe and a substantial reduction in tangential force of grinding is achieved [6, 10]. The complete elimination of the effect of air boundary layer on cutting fluid delivery is found possible by using the scraper board at 20° [12]. Mondal et al. have observed the air pressure by keeping the pneumatic barrier nozzle at 30°, 45° and 60° angular distance from the grinding zone and the lowest air pressure is noted at 30° polar angle of pneumatic nozzle among the three tested positions. Also flow of cutting fluid through the grinding zone is found to improve with the use of pneumatic barrier compared to the conventional flood cooling [13]. But the effect of advancement of pneumatic nozzle towards the grinding zone on the process performance and which one is more suitable among scraper board and pneumatic barrier method is not yet carried out. In the present work, novel efforts have been made to observe the grinding performance by preceding the pneumatic barrier system along with fluid delivery nozzle towards grinding zone and compare its effect with the scraper board system in order to find the better method of the fluid delivery system. The development of Fuzzy model and the relevant statistical analysis in this kind of research is also original.

2. Experimental Setup and Details

The experimental setup used in the investigation is given in Table 1. Results are noted for 10 passes of up-grinding operation with a wheel speed of 29.3 m/s, infeed 20 μm, table feed 7.5 m/min and coolant flow rate of 0.32 litre/s through conventional flood nozzle. Experiments are performed with two different sets as described below.

In one set, two kinds of nozzles, one is for delivering compressed air (termed as the pneumatic nozzle) and another is for sending grinding fluid, are taken together. As the air boundary layer reformation is found to start close to 20° after the air breaker, therefore, the coolant delivery nozzle is set 15° ahead of the pneumatic nozzle which sends compressed air as shown in Figure 1a and Figure 1b [12]. In another set, fluid delivery nozzle and scraper board (SB) is taken together where the fluid delivery nozzle is set 15° ahead of scraper board in the direction of the grinds zone as showed in Figure 1a and Figure 1c. The pressure and flow rate out of the coolant delivery nozzle is 3.5 kPa and 150 ml/s. A hard and thick paper board has been used as a scraper board in the experiment which has been maintained at 0.125mm distance from the cutting surface of the wheel. Paper scraper is used here to divert the rotating air around the wheel and accidentally if it touches the wheel, is not going to affect the grinding performances by increasing the 'wheel loading'. The pneumatic barrier (PnB) has been developed by issuing an air jet of high pressure at 30° angle with the horizontal plane. The high-pressure jet of the air has been prepared by a single stage compressor where nearly 5 kPa pressures at the nozzle - face is maintained throughout the experiment. This pressure is measured by Prandtle type Pitot tube and U-tube manometer arrangement. This jet impinges on the wheel surface and directed to oppose the rotating air around the wheel [7, 8]. A scraper board is also employed like the pneumatic barrier to deflect the air layer rotating around the wheel. After minimizing the air around the wheel, the coolant jet is impinged into the grinding zone. Experiments are performed by locating these two different sets at 45°, 60° and 75° away from the grinding zone. The various orientations at which coolant delivery nozzle, pneumatic barrier and scraper board is positioned is given in Table 2. Further, proceeding of the set of scraper board and fluid delivery nozzle ahead of 45° towards grinding zone is not possible as moving workpiece may entangle it during the operation. All the experiments are repeated thrice and the average of them is considered in the results.

In the present experiment specific energy (e) is calculated as follows.

$$e = \frac{Machining\ power}{Material\ removal\ rate} = \frac{Ft \times Vc}{b \times t \times Vw} \quad (1)$$

Where F_t = Tangential force (N)
V_c = Velocity of grinding wheel (m/s)
V_w = Table feed (m/min)
b = Width of workpiece (mm)
t = Infeed (μm)

Table 1. *Details of machinery and equipment used in the experiment.*

Sl. No.	Machine/equipment	Description/specification
1.	Surface grinding machine	Wheel Speed: 29.3 m/s Infeed resolution: 1 μm Table feed: 7.5 m/min
2.	Grinding Wheel	Specification: AA46/54K5V8 Size: ϕ200 x 20 x ϕ31.75 (mm)
3.	Differential U-tube manometer	Manometric fluid: Water
4.	Workpiece	Material: Low alloy steel Size: 100×55×6 (mm) Hardness: 26 HRC Composition: C- 0.1909%, Si- 0.1080%, Mn- 0.93225%
5.	Wheel dresser	Single point 0.5 carat, Diamond dresser
6.	Force Dynamometer	Range: 0.1 kgf - 100 kgf

Sl. No.	Machine/equipment	Description/specification
		Resolution: 0.1 kgf
7.	Depth gauge	Least Count: 0.001mm
8.	Dial indicator	Least Count: 0.001mm
11.	Vernier calliper	Least Count: 0.001mm

Table 2. *Orientations of scraper board and pneumatic barrier nozzle along with the coolant delivery nozzle.*

Position of coolant delivery nozzle (a)	Position of scraper board/ pneumatic barrier (b)	Abbreviated form used in the work (a+b)
45°	60°	SB1 / PnB1
60°	75°	SB2 / PnB2
75°	90°	SB3 / PnB3
45°	-	Conven

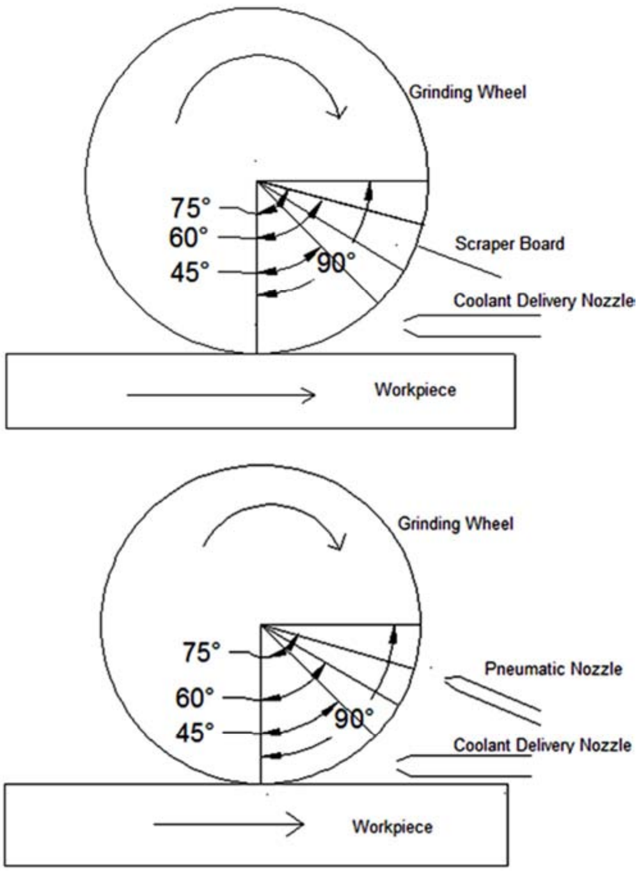


Figure 1a. *Schematic diagram of positioning scraper board and pneumatic barrier nozzle.*

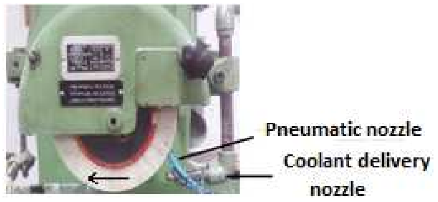


Figure 1b. *Arrangement of pneumatic barrier and coolant delivery nozzle.*

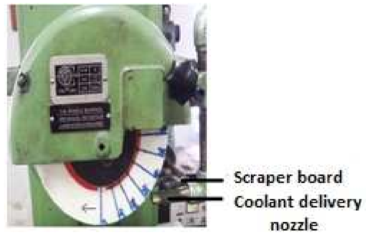


Figure 1c. *Arrangement of scraper board and coolant delivery nozzle.*

3. Results and Discussions

The phenomenological concept of the existence of rotating air and deflection of it by the scraper board and the pneumatic nozzle is given in Figure 2. The existence of air boundary around the wheel obstructs the entry of coolant into the grinding zone. This rotating air is deflected by the solid boundary of the scraper board as well as by a high-speed jet of air issued from a nozzle as shown in Figure 2. Therefore, the entry of coolant into the grinding zone may increase which subsequently may reduce the friction between two meeting surfaces of grinding wheel and workpiece. But which method is more effective in increasing lubrication and cooling into the grinding zone is determined by subsequent experimentation. How the advancement of scraper board and pneumatic barrier affects the lubrication into the meeting surfaces is also studied.

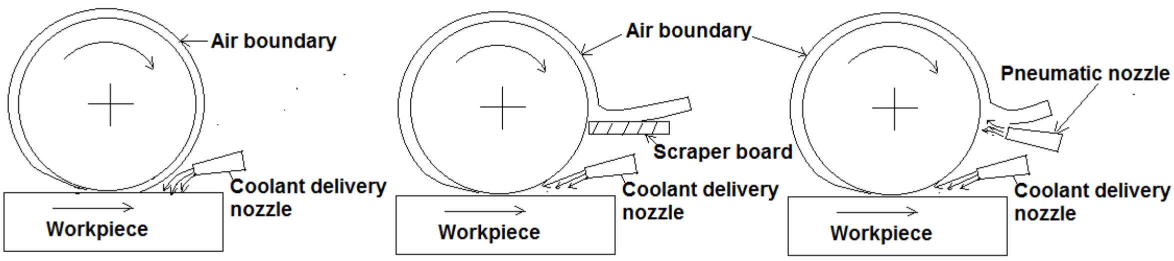


Figure 2. *Phenomenological concept of deflection of rotating air.*

3.1. Force of Grinding

Usually, two components of grinding forces are measured, tangential (Ft) and normal force (Fn) components. High tangential force leads to thermal damage of the workpiece due to the high amount of heat generation and the high quantity of wheel wear. Large normal force results in high chatter [14]. Figure 3 shows the experimental results of the tangential force of grinding. When a wheel rotates, the air is carried along the wheel due to the viscous effect and an air layer is formed around which obstructs the entry of the coolant jet into the grinding zone [10, 12]. The rotating air layer is obstructed by two methods – by the pneumatic barrier and a scraper board [Figure 2]. When these air deflectors are used against the grinding wheel, they restrict some amount of rotating air, which hinders the proper impingement of coolant into the grinding zone [2, 6-8]. Test results are obtained by placing scraper boards or pneumatic nozzle at three different locations along the wheel periphery. At all locations, the requirement of the tangential force is found to be less with the use of scraper board over the pneumatic barrier which demands the entry of more coolant into the grinding zone and as a result, the friction between wheel and workpiece reduces. The admission of more coolant into the grinding zone occurs may be due to the more decrease of air pressure around the wheel by a scraper board.

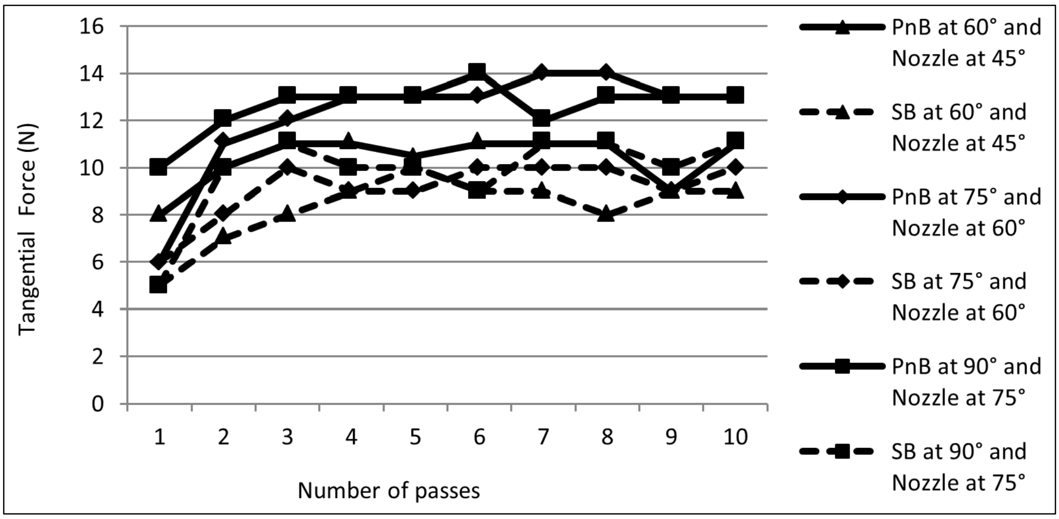


Figure 3. *Tangential force of grinding with pneumatic barrier and scraper board at various locations along the wheel periphery.*

When both types of air deflector are advanced separately towards grinding zone, the force of grinding reduces. It happens because when the rotating air is deflected by any scraper board or pneumatic barrier, after a certain peripheral distance the air boundary layer regenerates [11, 12]. With the advancement of air deflectors towards grinding zone, the origin, from where the regeneration air boundary layer starts, also advances and furthermore does not get enough space thereafter to rebuild its full strength. Therefore, the hindrance to the entry of coolant into wheel-workpiece interface becomes less, more fluid gets a chance to enter and as a consequence, the tangential force of grinding reduces. Figure 4 and Figure 5 demonstrate the average tangential force and the normal force of 10 passes of up-grinding at various locations of scraper board and pneumatic barrier along with the coolant delivery nozzle. The normal force of grinding is also found to decrease with the advancement of pneumatic barrier and scraper board towards the wheel-work meeting zone. Table 3 shows the percent improvement of grinding forces using scraper board over the pneumatic barrier. The scraper board is found to be more effective in reducing the both Ft and Fn. It may be attributed to the part of the fluid, used in the pneumatic barrier, is carried along with the wheel due to viscous effect. When a fluid is issued from a nozzle, a part of it outside the stream tube may not have the same velocity as within it. Those fluids with less energy, outside the stream tube, may be carried along with the wheel, which contributes to rebuilding the air boundary and extend some hindrance to coolant flow. Also after impinging of jet of air on the surface of the wheel, it may get scattered and a portion of it may again be carried along with the wheel and contribute to the rebuilding of a thin air layer [Figure 6]. As a result, comparatively less amount of coolant gets entry into the grinding zone.

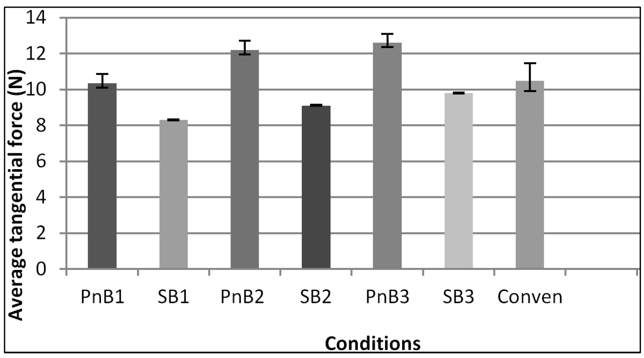


Figure 4. *Average tangential force of grinding at various conditions.*

Table 3. *Improvement of grinding forces using scraper board over pneumatic barrier.*

Position of scraper board or pneumatic barrier with respect to grinding zone	Percent decrease in average tangential force with the use of scraper board than pneumatic barrier	Percent decrease in average normal force with the use of scraper board than pneumatic barrier
60°	25	20
75°	34	33
90°	27	8

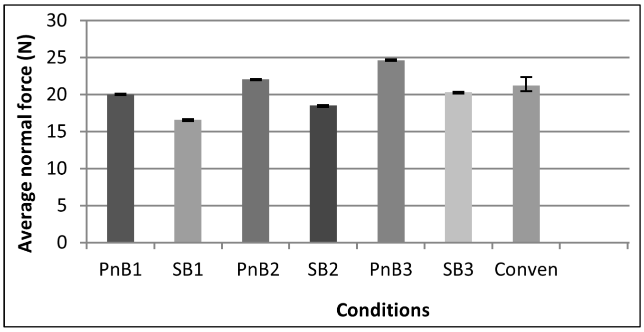


Figure 5. *Average normal forces of grinding at various conditions.*

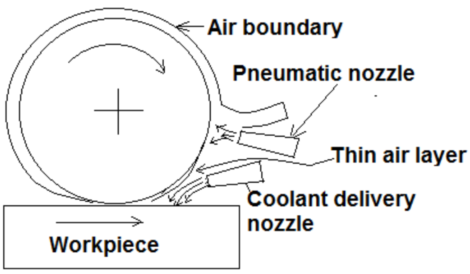


Figure 6. *Formation of thin layer of air after the pneumatic nozzle.*

3.2. Specific Energy

The specific energy is also an index of grindability. High specific energy indicates high temperature generation, less cooling, and lubrication, low material removal rate. It is proportional to the tangential force when the velocity of grinding wheel, wheel infeed, and table feed are unaltered. So the consequences occur due to the variation of tangential force implies to specific energy also. In the present experiment, it is found that use of scraper board can reduce the specific energy requirement compared to conventional flood cooling and pneumatic barrier method [Figure 7]. Nearly 20% decrease of specific energies by comparing with pneumatic barrier is observed with the use of scraper board at 60° locations. Further, advancement of scraper board towards the direction of the grinding zone also found to reduce this energy. The specific energy reduces by about 15% when it is employed at the location of 60° than that of at 90°.

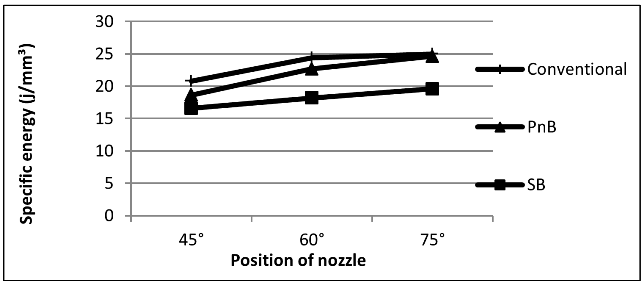


Figure 7. *Specific energy of grinding at various conditions.*

3.3. Surface Roughness

The quality of surface finish is one of the important parameters of the grinding process. Surface roughness decrease with the increase of lubrication into the grinding zone [14, 15]. As the flow of coolant increases of the mating surface of the grinding wheel and workpiece due to the use of a scraper board, lubrication also increases between them which results in improvement of surface quality. Again, with the entry of more fluid into contact zone, the grain life of wheel increases. When the fluid enters less, the fracture of grains occurs early and thereby increases the mean grain spacing along the motion, consequently roughness increases [2]. Nearly 11.8% of the decrease of average surface roughness (Ra) value is monitored when scraper board is employed behind the nozzle in comparison with the use of pneumatic barrier by keeping them at 60° location. The percent decrease in Ra value at various locations of scraper board in comparison with pneumatic barrier is shown in Table 4. The percent decrease in Ra value decreases when the scraper board or pneumatic barrier which is employed to deflect the rotating air is moved away from grinding zone. As much as these are placed away from grinding zone, the chances of reforming of air boundary layer and reinforcing the strength of it may increase resulting in the less entry of coolant into grinding zone and thereby increases surface roughness. On the contrary, with the advancement of these air deflectors towards contact zone, coolant enters more which reduces the friction between wheel grits and workpiece and increases wheel speed simultaneously.

Table 4. *Percent decrease in Ra value at various positions of scraper board along the wheel periphery in comparison with pneumatic barrier.*

Position of scraper board or pneumatic barrier with respect to grinding zone	Percent decrease in Ra
60°	11.8
75°	5.9
90°	5

From the experimental results as shown in Figure 8(a), it is concluded that the use of scraper board can improve the surface quality better than the use of pneumatic barrier and conventional flood cooling. This may be due to the decrease of cooling and lubrication at contact zone in case of conventional flood cooling and flood cooling with pneumatic barrier resulting in additional chip redeposition, burn and indentation marks on the ground surface [Figure 8(b)]. Further, better surface quality can be obtained when scraper board or pneumatic barrier positions are preceded towards grinding zone. A 21% decrease in Ra value is observed at 60° position of scraper board when compared with the 90° position of it.

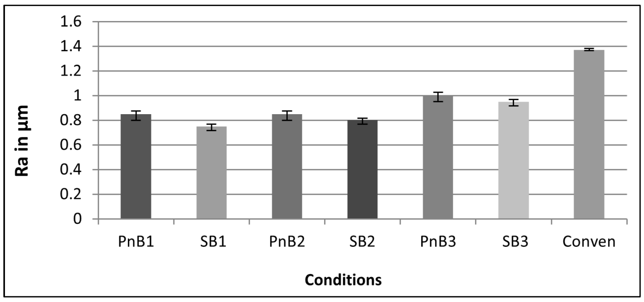
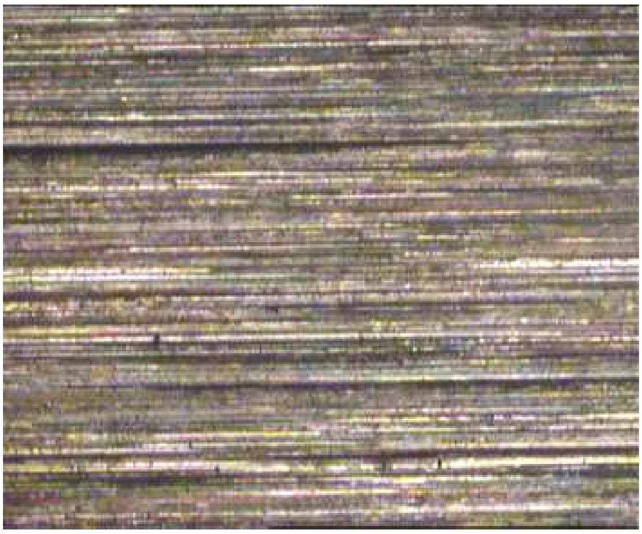
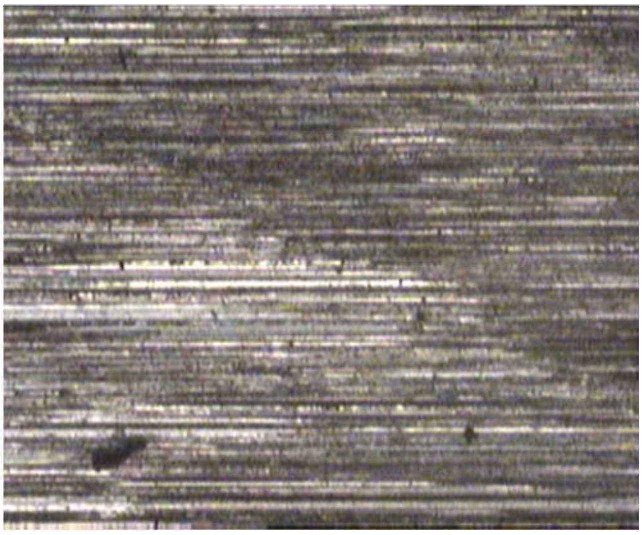


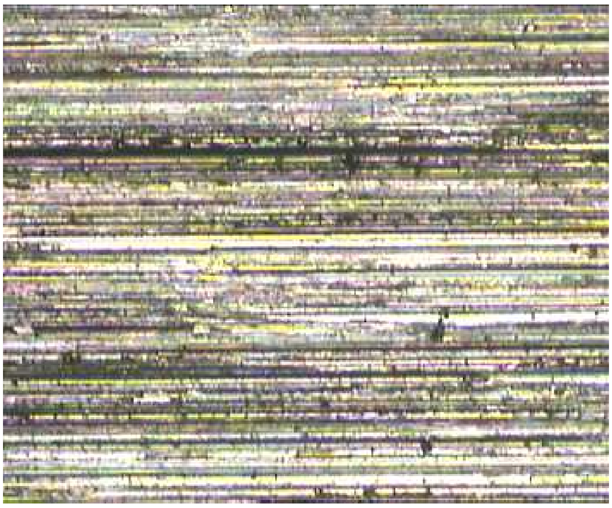
Figure 8(a). *Average surface roughness using a scraper board and pneumatic barrier.*



Flood cooling with SB



Flood cooling with PnB



Conventional flood cooling

Figure 8(b). *Comparison of ground surface at different grinding conditions after 10 grinding passes and nozzle at 45°.*

4. Statistical Analysis of the Results

In this work, the grinding performance test is carried out in two different methods, namely, scraper board and pneumatic barrier method. So it is required to find if there is any significant difference between these two methods or treatments. Three levels of grinding performance results with three replications at each level of performance result are taken.

The analysis of variance (ANOVA) for the tangential force, specific energy and surface roughness is shown in Table 5, Table 6 and Table 7 respectively. The between-treatment mean square of the tangential force and specific energy is found many times larger than the within-treatment. This indicates the treatment means are not equal. Further, since the P- value is less than 0.05 for the tangential force and specific energy, the null hypothesis is rejected at the 95% confidence level. Again, since the P- value for average surface roughness is greater than 0.05, there is not a statistically significant difference between the mean of scraper board and pneumatic barrier treatment and hence alternative hypothesis is rejected. In the operation of conventional wet grinding, due to early rounding-off of the grit-edges, the surface becomes smoother but temperature and residual stress increases which hamper the surface integrity. The flood cooling with the scraper board improves the introduction of fluid more effectively, so cooling and lubrication improves which in turn gives better surface integrity. Though the more fluid is possible to introduce in the grinding zone by scraper board compared to pneumatic barrier method, due to the wheel loading and re-deposition no significant changes in Ra value is observed but the temperature and residual stress decrease appreciably. Therefore, it can be concluded that almost similar surface roughness can be obtained by expending less tangential force and specific energy by scraper board method than the pneumatic barrier.

Table 5. *ANOVA for the tangential force.*

Source of variation	Sum of Squares	Degrees of Freedom	Mean Square	F	P - value
Between Groups	10.40167	1	10.40167	11.22482	0.02856
Within Groups	0.926667	4	0.926667		

Table 6. *ANOVA for the specific energy.*

Source of variation	Sum of Squares	Degrees of Freedom	Mean Square	F	P value
Between Groups	41.60667	1	41.60667	11.22482	0.02856
Within Groups	14.82667	4	3.706667		

Table 7. *ANOVA for the surface roughness.*

Source of variation	Sum of Squares	Degrees of Freedom	Mean Square	F	P value
Between Groups	0.006667	1	0.006667	0.727273	0.441823
Within Groups	0.036667	4	0.009167		

5. Analysis of the Results by Coefficient of Variation (CV)

The effect of scraper board in improving grinding performances with comparison to pneumatic barrier has been found better and discussed in the previous section 3. Invariably, the scraper board method has a pivotal role in breaking the rotating air around the grinding wheel in the introduction of grinding fluid into grinding zone as it is seen in the experimental results. The results of all the experiments are thoroughly investigated in order to establish the overall influence of 'scraper board method' by measuring their variations. Two different methods adopted, here, produce different results due to their diverse capability of breaking the air layer. A relative measure, in this context, is generally used for comparison. Co-efficient of variation (CV) is considered here for more logical dimension less relative measure of dispersion. The values of sample mean, standard deviation and CV is shown in Table 8. Considering all experiments, the CV values of scraper board (SB) is found more consistent in comparison to pneumatic barrier (PnB) method. Comparative analysis demonstrates that 'scraper board method' is better for improving grinding performances by reducing air flow around the grinding wheel. The values of parameters when scraper board and pneumatic barrier is placed at 60° position are considered for the analysis.

Table 8. *Statistical analysis of grinding performance with scraper board and pneumatic barrier.*

Parameters	Experimental conditions	Sample Mean (μ)	Std. Deviation (σ)	CV in% [σ/ μ]*100	Percent improvement in CV with SB
Ft	PnB	11.7	1.13578	9.7	
	SB	9.06667	0.750555	8.27	14.74
Fn	PnB	22.2	2.30651	10.38	
	SB	18.6	1.65227	8.88	14.45
E	PnB	23.4	2.27156	9.07	
	SB	18.1333	1.50111	8.27	8.82
Ra	PnB	0.9	0.0866025	9.62	
	SB	0.83333	0.104083	12.49	29.83

6. Fuzzy Models

Based on the experimental findings the Fuzzy models are shown in Figure 9 through Figure 11. Input values are positions of pneumatic barrier (PnB) and scraper board (SB). Output values are an average tangential force (F_t), the surface roughness (Ra), specific energy (e) and grinding ratio (Gr). For input and output values triangular membership functions are used in Mamdani based Fuzzy reasoning using MATLAB R2012a. Input and output functions are taken in such a way so that theoretical hypothesis and experimental findings well match with the model. Hypothetically, with the incorporation of cooling and lubrication into grinding zone, grinding parameters may enhance which is also found to improve in the present experiment with the entry of additional lubricant by the scraper board method. From the model, it is easily explained that with the employment of scraper board, the tangential force of grinding, surface roughness and specific energy reduces than that of the pneumatic barrier.

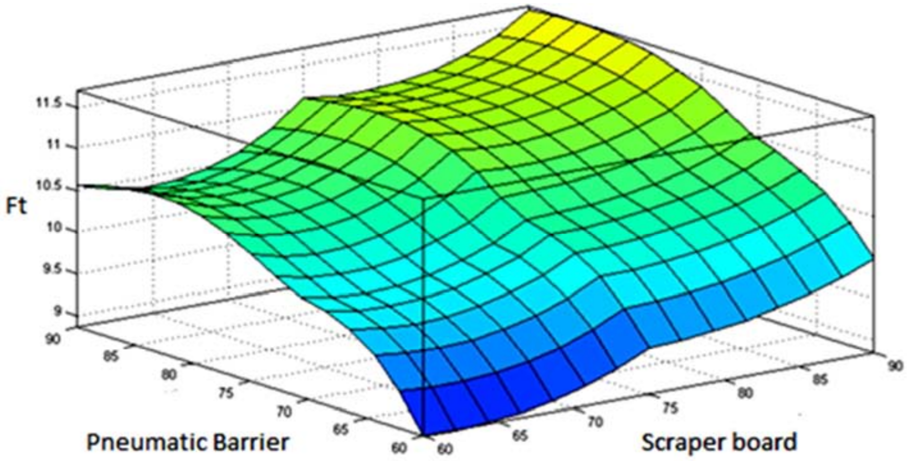


Figure 9. *Fuzzy model of tangential force of grinding (F_t) with the employment of scraper board (SB) and pneumatic barrier (PnB) with conventional flood cooling.*

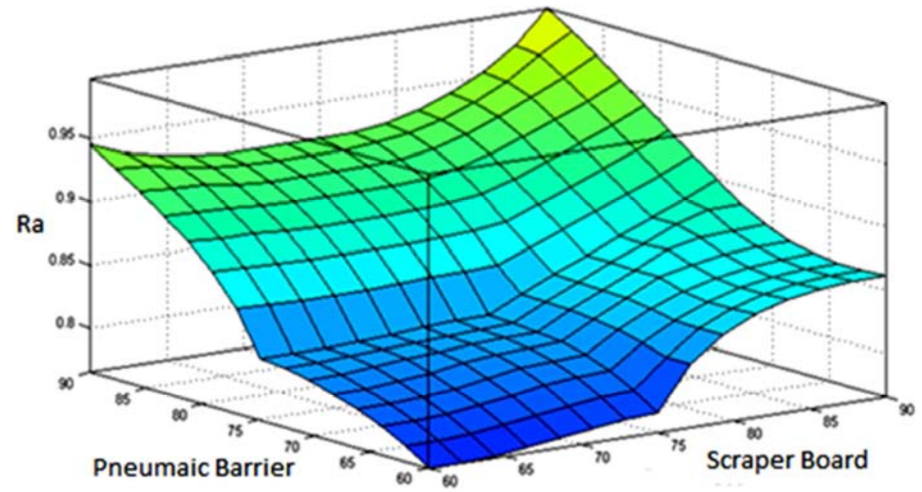


Figure 10. *Fuzzy model of surface roughness (R_a) with the employment of scraper board (SB) and pneumatic barrier (PnB) with conventional flood cooling.*

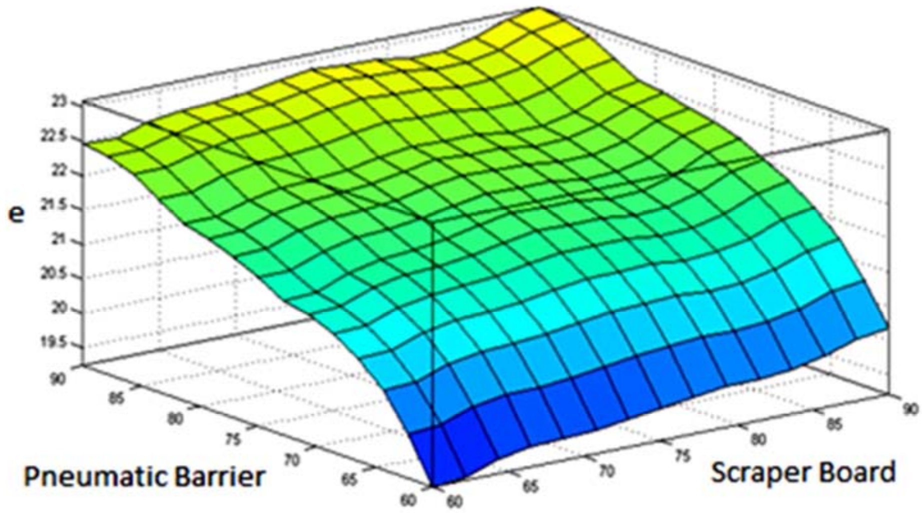


Figure 11. *Fuzzy model of specific energy (e) with the employment of scraper board (SB) and pneumatic barrier (PnB) with conventional flood cooling.*

7. Comparative Study

The present investigated results are compared with the result obtained by Mondal et al. in which only pneumatic barrier technique is taken care of [7]. In Figure 10, Ra value obtained by Mondal and in the present experiment is plotted. Comparing the experimental results between the pneumatic barrier and scraper board method, it is found that quality of surface engendered in terms of surface roughness is virtually equal in both the processes [Figure 12 and Table 10]. However, amelioration in grinding force is remarkable with the scraper board which denotes the efficacious cutting and retaining of grit sharpness to a further extent, albeit the grinding and other boundary conditions are virtually similar in both the experiments. So, virtually homogeneous surface quality is obtained by earlier researcher and in the present investigation by pneumatic barrier method. Further, both the methods are withal found to engender kindred surface quality but less grinding force and hence, less specific energy is required when scraper board is employed. Table 9 shows the various grinding and boundary conditions of the present and past experiments by the earlier researcher.

Table 9. *Grinding and other boundary conditions in the earlier and present investigation.*

Experiments	Grinding and other boundary conditions
Experiment by Mondal et al. [7]	Wheel speed: 30 m/s Wheel specification: AA 46/54 K5 V8 Size: ϕ200 x 13 x ϕ31.75 (mm) Workpiece material: Low alloy steel Grinding fluid: water soluble oil (1:20) Depth of cut: 20 µm
Present Experiment	Wheel speed: 29.3 m/s Wheel specification: AA46/54K5V8 Size: ϕ200 x 20 x ϕ31.75 (mm) Workpiece material: Low alloy steel Grinding fluid: water soluble oil (1:40) Depth of cut: 20 µm

Table 10. *Percent improvement of surface quality in present investigation with scraper board method with comparison to pneumatic barrier method.*

Experiment	Percent decrease in Ra value by a scraper board with compared to pneumatic barrier
By Mondal et. al. [7]	6.25
Present	11.8

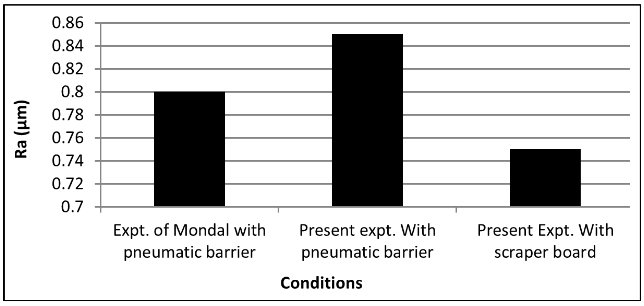


Figure 12. *The average surface roughness value at various conditions of grinding.*

In Figure 13 the present and earlier study [7] of normal force of grinding by using a pneumatic barrier technique are plotted together. The study of normal force by restricting the rotating air flow by a scraper board is likewise plotted along with. Similar curves are generated with the pneumatic barrier. The curve obtained by keeping the pneumatic nozzle at 60° is found very proximate to the curve of that by Mondal [5]. It establishes that when the nozzle is moved forward direction towards grinding zone up to 60° gives a similar effect to the application of pneumatic nozzle at an optimized angle (θ=30°) as done early. However, the effect of scraper board at 60° position supersedes the effect of angle optimization of the pneumatic barrier. Unlike proceeding of pneumatic barrier set up to 30°, advancing the scraper board arrangement causes the moving workpiece to entangle with it. A statistical analysis for comparison of the results to check the supremacy of scraper board over the pneumatic barrier is shown in Table 11. Utilization of scraper board in wet grinding has been observed to produce the better result.

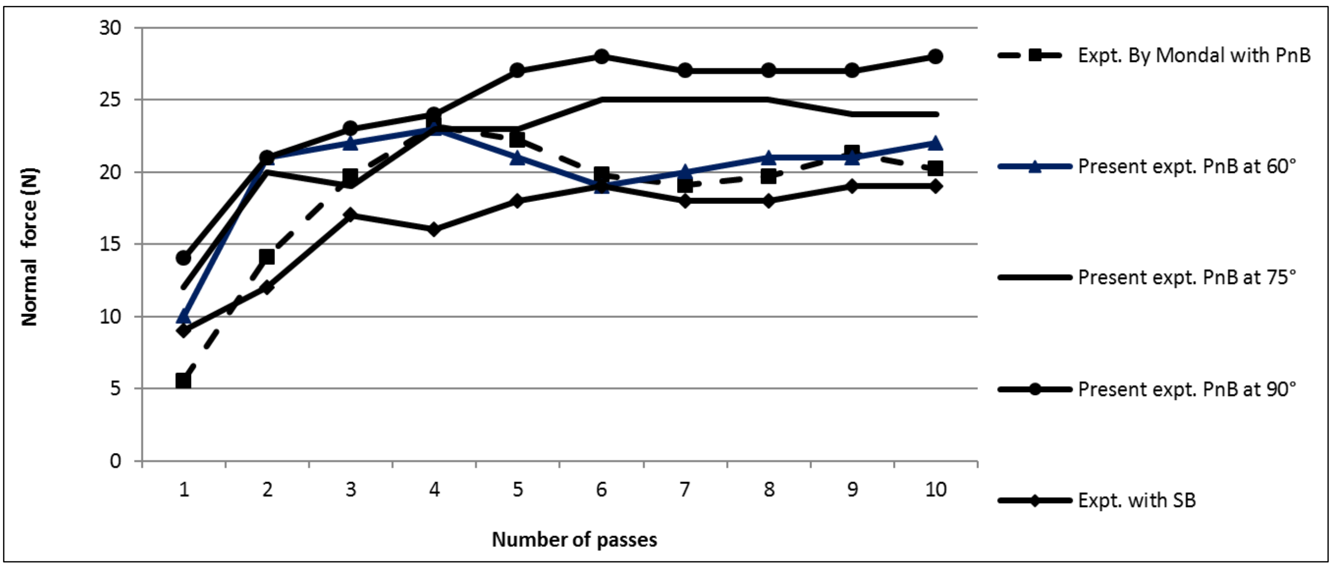


Figure 13. *Normal grinding force in earlier and present investigation.*

Table 11. *Statistical analysis of normal grinding force at various experimental conditions.*

Conditions	Sample Mean	Std. Deviation	CV	Percent improvement in CV with respect to expt. By Mondal
Expt. By Mondal with PnB	18.482	5.1562	0.278985	
Present expt. PnB at 60°	19.5	3.8658	0.198246	28.93
Present expt. PnB at 75°	22.0	4.08248	0.185567	33.47
Present expt. PnB at 90°	24.6	4.40202	0.178944	33.85
Expt. with SB at 60°	16.5	3.37474	0.20453	26.68

8. Conclusion

The better method of suppression of air boundary around a rotating grinding wheel is suggested. Experiments and statistical analysis are conducted to compare the performance of the scraper board and pneumatic barrier. The use of a scraper board proved to be more effective than the pneumatic barrier in reducing the requirement of tangential force and specific energy of grinding. The requirement of tangential force and specific energy are reduced by 25% and 20% respectively when SB and PnB are positioned separately at 60° location. Consequently, the product quality and productivity increases.

Due to the better suppression of air barrier by the scraper board, more coolant can enter into the contact surfaces which in turn enhances the cooling and lubrication between the grinding wheel and workpiece further. Hence, more reduction of temperature and residual stress is possible, which leads to the better surface integrity of the component. The advancement of nozzle towards grinding zone increases the process performance. It increases further when accompanied by either a scraper board or pneumatic barrier system. However, the former proved to give better performance than the later. Hence, the use of scraper board of proximity to grinding zone is suggested.

The Mamdani based Fuzzy reasoning using triangular function is found to match well with the experimental data. So, it can be used for the prediction of grinding force, specific energy and surface roughness employing scraper board or pneumatic barrier system.

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