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IMPROVING GRINDABILITY OF TITANIUM GRADE 1 USING A PNEUMATIC BARRIER

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Abstract: Grinding fluid application is important to control thermal related problems while grinding titanium alloys. Conventional fluid delivery systems are not able to deliver grinding fluid deep into the grinding zone because of the presence of a stiff air layer around a rotating grinding wheel. A newly developed pneumatic barrier system is used in this experimental investigation to penetrate the air layer so as to deliver fluid into grinding zone. Dry, flood cooling and flood cooling with pneumatic barrier conditions are used to explore the influence of these environmental conditions on grindability of titanium grade 1 workpiece. It is seen that under flood cooling using pneumatic barrier, better grinding performance is obtained than conventional flood cooling condition.

Keywords: Grinding, pneumatic barrier, grinding fluid, titanium alloy, air layer.

1. INTRODUCTION

Titanium grade 1 is a super alloy that is widely used in airframe components, components of chemical desalination plants, cryogenic vessels, heat exchanger tubes, surgical implants, etc. [1]. Generally, super alloys exhibit high strength at elevated temperature, good resistance to oxidation, good impact strength, castability and less density. However, thermal conductivity of many super alloys is only 10% - 30% of that of steel [2]. Due to high strength, work hardenability, low thermal conductivity and large specific heat, several difficulties in grinding such as surface damage, intense wheelloading, low grinding ratio, etc., are also reported [3-5].

Machining and grinding of titanium and its alloys are difficult due to their chemical reactivity beyond 350°C, low thermal conductivity and high hot strength [5,6]. At high temperature, titanium has strong affinity with nitrogen, oxygen and carbon. It was reported [6] that nitrogen, oxygen and carbon will go into solution with titanium in the molten state and tend to make the material harder, stronger and less ductile at a temperature of 800°C. Due to this reason, when silicon carbide wheel is used to grind titanium, TiC and silicon are produced through chemical reaction [7].

During grinding of titanium using conventional grinding procedures, many difficulties were observed [8], such as excessive wheel wear resulting in loss of contact of the wheel with the work, surface reaction between the work and the wheel producing high temperature, causing a decrease in wheel life and surface burn, coating of wheel with titanium reducing its abrasive action, etc. Combination of above mentioned difficulties result in poor surface quality. Grinding ratio of titanium alloy was found to be within the range of 3 to 9. It was suggested [8] that improvement in grindability might be achieved by the reduction of wheel speeds, the application of specific coolants and lubricants, and restricting abrasive grain mesh sizes between 60 and 80. It was also mentioned that use of appropriate wheel grit material and careful selection of infeed might improve grindability.

Grinding fluid plays a significant role to control thermal problems during grinding. However, flood cooling system, which is commonly used in industry, are not capable enough to deliver grinding fluid satisfactorily into grinding zone due to presence of stiff air layer around the rotating grinding wheel [9,10]. Besides studying the nature of air layer around a grinding wheel, a number of attempts was made to overcome problems caused by it. The boundary air layer might be largely suppressed by a scraper plate or board; various designs of scraper plate were detailed by Baturin [11]. Use of scraper board and a rexine pasted wheel face yielded better grinding performance than that of a bare wheel as reported by Das and others [12]. Aerodynamic baffle, a special type scraper plate arrangement, was also introduced [13] to reduce air velocity around a grinding wheel significantly. The gap between scraper plate and wheel periphery needs be kept very small, and needs frequent adjustment, which is reported to be difficult to implement in industry [9,14].

To reduce grinding temperature, cutting fluid has to enter deep inside the grinding zone. For measuring the effective flow of cutting fluid through grinding zone, Akiyama et al. [15] found out an 'effective flow rate' through grinding zone, and 20 – 50% of the supply flow rate was estimated to be the effective flow rate. Engineer et al. [16] developed a test rig, and using the rig, they observed that only 4 to 30% of applied fluid was passing through the grinding zone. Flow of grinding fluid through grinding zone is dependent on several factors, such as position of fluid delivery nozzle, fluid velocity, flow rate, wheel porosity, etc. [17]. Some other researchers [12,18-21] pasted rexine (artificial leather) on both sides of the grinding wheel for controlling suction of air through porous faces of grinding wheel. They reported that rexine pasted wheel had performed better compared to a normal grinding wheel. To develop an efficient cooling and lubricating system, several nozzle and fluid supply strategies were developed, such as free jet nozzle, shoe nozzle, spot jet nozzle, spray nozzle, etc. [9].

Ebbrell et al. [22] developed a computational fluid dynamics model of layer of air boundary around the grinding wheel to show that the direction of air layer was along with the wheel rotation direction, and after striking the workpiece at wheel workpiece contact surface, the direction of air flow was reversed. From their model, two different directions of air layer were observed, and for effective fluid delivery, the nozzle was required to be kept above the reverse flow area. To overcome the detrimental effects of air layer around grinding wheel, and for deep penetration of fluid inside grinding zone, typical fluid delivery nozzles were also developed [23-26]. Single flow nozzle, round or rectangular in shape, was developed by Webster et al. [25] for generating long coherent jets of grinding fluid.

In a review work, different types of grinding fluid delivery techniques were discussed [27] to compare their effectiveness. It was reported [28,29] that improvement of fluid flow through grinding zone may be achieved after using a newly developed pneumatic barrier setup along with flood cooling system. In this method, one pneumatic jet was used to control air layer pressure around rotating grinding wheel, and flood cooling was used to deliver fluid into grinding zone. Performance of the compound or multi-nozzle using significantly less discharge of fluid was tested in another work [30]. Use of pneumatic nozzle was compared with a compound or multi-nozzle in terms of their effectiveness to enhance grinding performance [31]. At a high speed of fluid jet through multi-nozzle, fluid delivery through the grinding zone was observed to be better than the pneumatic barrier system. Mahata et al. did another work [32] to evaluate relative performance of grinding by using conventional flood cooling, multi-nozzle and mist cooling, and reported that multi-nozzle performed better.

Grinding performance was also studied applying grinding fluid through multi-nozzle for grinding titanium grade 1 using SiC wheels to obtain some success [33]. Another exotic material, inconel 600 could be ground successfully [34] using an alumina wheel by applying water soluble oil as a grinding fluid employing the pneumatic barrier.

In the present work, effects of dry, flood cooling and flood cooling with pneumatic barrier have been experimentally investigated in plunge surface grinding of titanium grade 1 work material using an alumina grinding wheel. Grinding performance has been evaluated by measuring grinding forces, studying grinding chips, ground surface quality and wheel wear.

2. EXPERIMENTAL CONDITIONS

Grinding experiments are carried out using surface grinding machine using alumina wheel. Grinding parameters and fluid delivery conditions are mentioned in Table 1.

Wheel velocity of 30 m/s and table feed of 7 m/min are maintained throughout the experiments. A constant infeed of 10 μm is chosen during grinding experiments for titanium Gr. 1 material. Three environmental conditions such as dry, flood cooling and flood cooling with pneumatic barrier are considered to observe its effects. Up grinding mode is followed for all the experiments. Ten numbers of grinding passes are undertaken for all the conditions.

For flood cooling, grinding fluid is passed through a conventional nozzle having 6 mm outer diameter, and placed 10 mm above the work surface to discharge fluid at 1000 ml/min. For flood cooling with pneumatic barrier setup, a pneumatic nozzle is positioned at a polar angle (θ) of 45^{o} with respect to wheel contact surface, and 10 mm from wheel periphery at a swivel angle (α) of 30^{o} as shown in Fig. 1. Rate of fluid flow through the nozzle is kept the same as that of flood cooling system to explore the beneficial effect of pneumatic barrier setup. The pneumatic pressure of 400 mm of water column (3.90 kPa) is employed through out these experiments considering substantial gain achieved at this moderate pressure as reported in one previous work [28].

Table1 Experimental condition

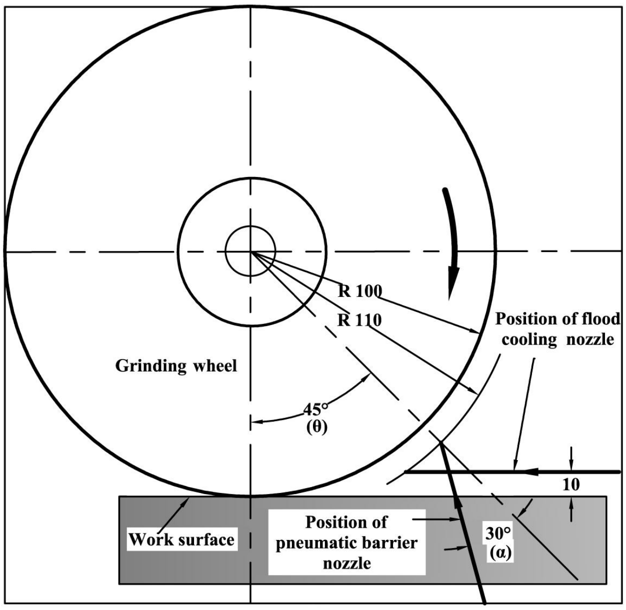
Grinding conditions	Mode: Up grinding Grinding wheel: AA46/54K5V8 Size: ϕ150 x 13 x ϕ31.75 Grinding velocity : 30 m/s Table feed: 7 m/min Infeed: 10 μm
Environment	Dry Wet with water soluble oil (1:20) with a flow rate of 1000 ml/min • Flood cooling • Flood cooling using pneumatic barrier
Parameters of pneumatic barrier	Polar angle (θ): 45^o Swivel angle (α): 30^o Pneumatic barrier pressure: 400 mm of water column (3.90 kPa)
Workpiece material	Titanium grade 1 Composition: 99.85% Ti, 0.01% N, 0.12% Fe, 0.02% O Hardness: 220 BHN
Workpiece size	120 mm x 65 mm x 6 mm

A strain gauge type dynamometer (make: Sushma, India, model: SA116) is used for measuring grinding forces. During each pass, tangential (Ft) and normal (Fn) force components are measured. Surface roughness of work surface is also measured after ten passes of up grinding at various grinding conditions using a Taylor Hobson make talysurf (model: Surtronic 3+). Ground surfaces are also observed by using a Mitutoyo, Japan make tool makers microscope. Grinding chips are collected during 9th pass, and observed using tool makers microscope to find out types of chips formed. Grinding wheel wear is measured using a dial indicator.

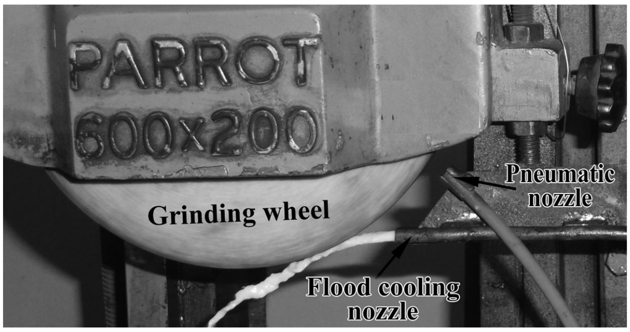
3. RESULTS AND DISCUSSION

Variation in grinding forces (in normal and tangential direction) at 10 μm infeed under different environment of dry, flood cooling, flood cooling with pneumatic barrier are shown in Fig. 2. In this figure, all the force components are found to be increasing for the initial few grinding passes, and then forces are stabilised. This is the usual characteristics of the grinding process. When no fluid is applied in grinding, both the grinding forces are naturally found to be higher in comparison with wet conditions due to absence of cooling and lubricating effects.

In flood cooling, both the grinding forces are lesser than that in dry grinding. It is seen that flood cooling with pneumatic barrier reduces the magnitude of both the tangential (Ft) and normal (Fn) forces considerably on the whole compared to conventional flood cooling system under the same grinding fluid discharge of 1000 ml/min. This may be due to deep penetration of grinding fluid into the grinding zone due to use of pneumatic barrier setup. The pneumatic barrier facilitates penetrate air layer formed to supply fluid deep inside the grinding zone. It results in reduction of friction between work surface, and grit and bonding materials due to lubricating effect of the fluid. This, in effect, may have resulted in less wheel wear and lowering of grinding forces indicating the effectiveness of using this pneumatic barrier setup. During grinding, comparatively less wheelloading is observed in case of flood cooling using the pneumatic barrier set up compared with the dry and conventional flood cooling conditions.



(a)



(b)

Fig. 1 Experimental Setup
[(a) Schematic, and (b) Photograph]

Roughness of ground surface in transverse direction under different environment is measured using talysurf. After 10 grinding passes, three readings are taken at three different positions of work surface. Average values of roughness parameters are presented in Fig. 3. Variation of average surface roughness (Ra), ten point average (Rz) and maximum peak to minimum valley (Rmax) surface roughness values are shown in Fig. 3.

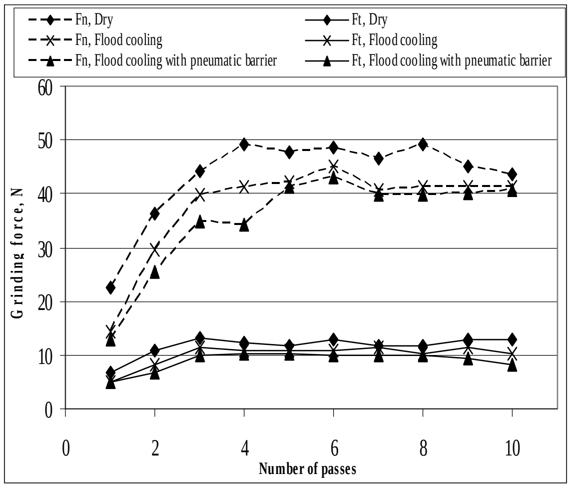


Fig. 2 Variation of grinding force with number of passes under different environment

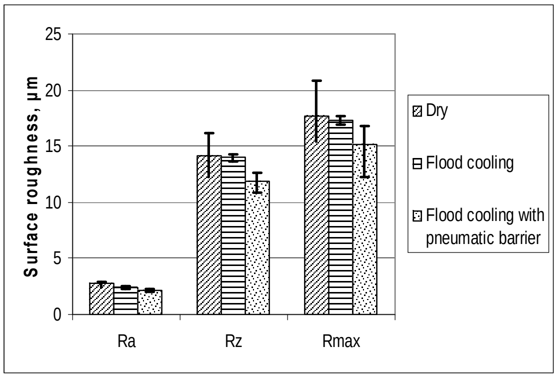


Fig. 3 Comparison of surface roughness in transverse direction after 10 grinding passes

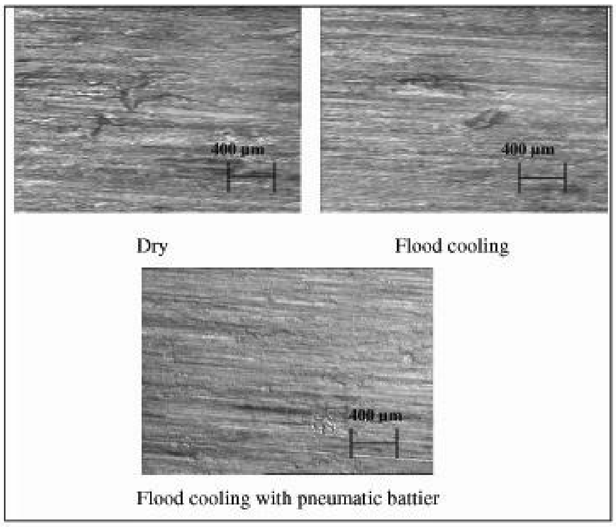


Fig. 4 Microscopic view of ground produced after 10th pass of grinding by using Al_2O_3 wheel

On the whole, surface roughness values of work surface obtained in dry grinding are higher than all other conditions. All the three roughness values of ground surface after grinding with conventional flood cooling are mostly lower than that of dry grinding, although, Rz and Rmax values under dry and this wet condition are comparable. The reason behind may be due to some beneficial effects of grinding fluid in terms of lubrication and cooling. It is observed that mean surface roughness values on the whole is somewhat lesser using flood cooling with pneumatic barrier than usual flood cooling system. This indicates that fluid may have penetrated relatively deep into the grinding zone to reduce grinding zone temperature which in turn does not cause Ti alloy to get hardened to some extent. Although grinding of Ti alloy is considered to be an abusive grinding, use of the pneumatic barrier facilitate obtain somewhat less surface roughness compared to that of dry and flood cooling conditions.

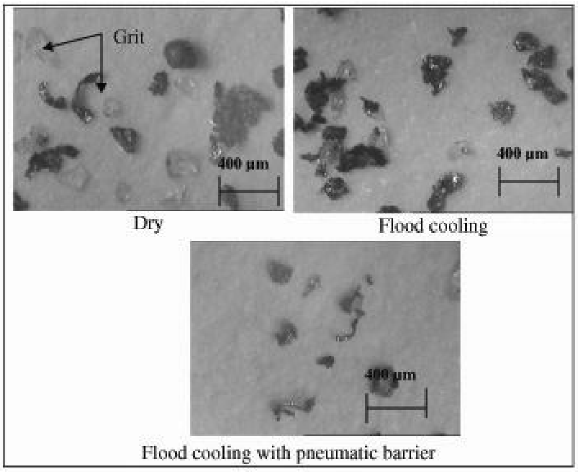


Fig. 5 Microscopic view of grinding chips of titanium Gr. 1 produced after 9th pass of grinding

Tool makers microscope is used for observing ground surfaces obtained after 10 grinding passes under different environment used in this work. Microscopic views of ground surfaces are shown in Fig. 4. Surface cracks, occasional light burning spots and chip redeposition are observed at dry grinding indicating high heat generation in grinding zone. In flood cooling, surface cracks are not observed, however, chip redeposition is found out. This indicates that flood cooling method can control grinding zone temperature only to a small extent. Surface obtained after using flood cooling with pneumatic barrier is better than dry and conventional flood cooling conditions. No surface cracks are observed in this grinding condition, indicating better grinding performance than that under dry and flood cooling conditions.

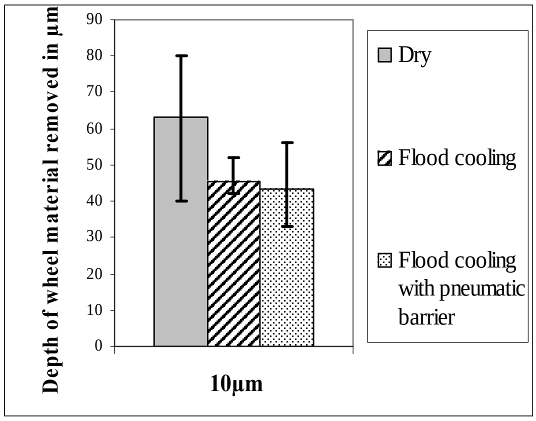


Fig. 6 Depth of wheel material removed after 10 grinding passes of titanium Grade 1

Grinding chips are collected during 9th pass of grinding at 10 µm infeed under dry and wet conditions. Microscopic views of chips are shown in Fig. 5. In dry and flood cooling conditions, most of chips are of slice type and short segmented type. Large numbers of dislodged grits are also observed. Slice type chips along with wheel grit indicate large scale wheel loading and wheel material removal. In flood cooling with pneumatic barrier, some favourable long curly chips are observed along with short segmented and slice types. Slightly less number of dislodged grits compared to flood cooling is observed after using pneumatic barrier. These indicate that after using flood cooling with pneumatic barrier dulling of grits may become slower, and wheel material removal may be lesser than that with dry and flood cooling system to a remarkable and to a marginal extent respectively.

Depth of wheel material removed is measured after 10 passes on titanium Gr. 1 work material under different environment, and results are represented in Fig. 6. At dry condition, depth of wheel material removed is substantially high compared to other wet conditions, indicating extensive grit dislodgement due to large grinding force and high grinding zone temperature. Depth of wheel material removed is comparable under two wet conditions.

5. CONCLUSIONS

From the present experimental investigation, following conclusions may be drawn.

- Surface cracks and chip redeposition on ground surface is observed during grinding of titanium Gr. 1 under dry condition at 10 μm. However, better ground surface is observed under wet grinding conditions.
- It is observed that grinding under flood cooling with pneumatic barrier exhibits requirement of somewhat less grinding force, less surface roughness and less wheel material removal with compared to dry and conventional flood cooling.

REFERENCES

[1] Midhani Product: Super Alloys; Titanium and Titanium Alloys, www.midhani.gov.in, 2011.

[2] Kovach, J.A. and Malkin S., Thermally Induced Grinding Damage in Superalloy Materials, Annals of the CIRP, Vol.37, No.1, pp.309-313, 1988.

[3] Kumar, K.V. and Shaw, M.C., Metal Transfer and Wear in Fine Grinding, Wear, Vol.82, pp.257-270, 1982.

[4] Turley, D.M., Factor Affecting Surface Finish when Grinding Titanium and a Titanium Alloy (Ti-6Al-4V), Wear, Vol.104, pp.323-335, 1985.

[5] Chattopadhyay, A.B., Machining and Machine Tools, Wiley India Pvt. Ltd., India. 2011.

[6] Palhade, R.D., Tungikar, V.B. and Dhole, G.M., Application of Different Environments in Grinding of Titanium Alloys (Ti-6Al-4V): Investigations on Precision Brazed Type Monolayered Cubic Boron Nitride (CBN) Grinding Wheel, Institution of Engineers (India) Journal–Production Engineering Division, Vol.90, pp.9-13, 2009.

[7] Yang, C.T. and Shaw. M.C., The Grinding of Titanium Alloy,, Transactions of the ASME, Vol.77, pp.645-660, 1955.

[8] Abkowitz, S., Burke, J.J. and Hiltz, R.H., Titanium in Industry– Technology of Structural Titanium, D. Van Nostrand Company, Inc., New York, 1955.

[9] Brinksmeier, E., Heinzel, C. and Wittmann, M., Friction, Cooling and Lubrication in Grinding, Annals of the CIRP, Vol.48, No.2, pp.581-598, 1999.

[10] Mandal, B., Majumdar, S., Das, S. and Banerjee, S., Predictive Modeling and Investigation on the Formation of Stiff Air-Layer around the Grinding Wheel, Advanced Materials Research, Advances in Materials and Processing Technologies, Vol.83-86, pp.654-660, 2010.

[11] Baturin, V.V., Fundamentals of Industrial Ventilation, Pergamon Press, 1972.

[12] Das, S., Sharma, A.O., Singh, S.S. and Nahate S.V., Grinding Performance through Effective Application of Grinding Fluid, Proceedings of the International Conference on Manufacturing, Dhaka, Bangladesh, pp.231-239, 2000.

[13] Catai, R.E., Silva, L.R.D., Bianchi, E.C., Aguiar, P.R.D., Zilio, F.M., Valarelli, I.D.D. and Salgado, M.H., Performance of Aerodynamic Baffles in Cylindrical Grinding Analyzed on the Basis of Air Layer Pressure and Speed, Journal of the Brazilian Society of Mechanical Science & Engineering, January – March, xxx, pp.47-50, 2008.

[14] Davies, T.P. and Jackson, R.G., Air Flow around Grinding Wheels, Precision Engineering, Vol.3, No.2, pp.225-228, 1981.

[15] Akiyama, T., Shibata, J. and Yonetsu, S., Behaviour of Grinding Fluid in the Gap of the Contact Area between a Grinding Wheel and a Workpiece, Proceedings of the Fifth International Conference on Production Engineering, Tokyo, pp.55-57, 1984.

[16] Engineer, F., Guo, C. and Malkin, S., Experimental Measurement of Fluid Flow through the Grinding Zone, Transactions of the ASME, Journal of Engineering for Industry, Vol.114, pp.61-66, 1992.

[17] Chang, C.C., Wang, S.H. and Szeri, A.Z., On the Mechanism of Fluid Transport across the Grinding Zone, Transactions of the ASME, Journal of Engineering for Industry, Vol.118, pp.332-338, 1996.

[18] Kundu, P.K., Das, S., Sinha, S. and Chowdhury, P.P., On Grinding Wheel Performance in Dry and Wet Conditions, Proceedings of the 4th International Conference on Mechanical Engineering, Dhaka, pp.19-24, 2001.

[19] Putatunda, S., Bandyopadhyay, A.K., Bose, T., Sarkar, S. and Das, S., On the Effectiveness of Applying Grinding Fluid in Surface Grinding, Proceedings of the National Seminar on Emerging Trends in Manufacturing, Banaras, India, pp.182-187, 2002.

[20] Sarmacharya, R.S., George, M.N. and Das, S., On the Grinding Wheel Performance through Minor Wheel Modification, Proceedings of the 18th AIMTDR Conference, Kharagpur, India, pp.156-161, 1998.

[21] Mandal, B., Majumdar, S., Das, S. and Banerjee, S., Formation of a Significantly Less Stiff Air-Layer around a Grinding Wheel Pasted with Rexine Leather, International Journal of Precision Technology, Vol.2, No.1, pp.12-20, 2011.

[22] Ebbrell, S., Woolley, N.H., Tridimas, Y.D., Allanson, D.R. and Rowe, W.B., The Effect of Cutting Fluid Application Methods on the Grinding Process, International Journal of Machine Tools and Manufacture, Vol.40, pp.209-223, 2000.

[23] Alberdi, R., Sanchez, J.A., Pombo, I., Ortega, N., Izquierdo, B., Plaza, S. and Barrenetxea, D., Strategies for Optimal Use of Fluids in Grinding, International Journal of Machine Tools and Manufacture, Vol.51, pp.491-499, 2011.

[24] Webster, J.A., Improving Surface Integrity and Economics of Grinding by Optimum

Coolant Application with Consideration of Abrasive Tool and Process Regime, Proceedings of the IMechE, Part B: Journal of Engineering Manufacture, Vol.221, pp.1665-1675, 2007.

[25] Webster, J.A., Cui, C. and Mindek Jr. R.B., Grinding Fluid Application System Design, Annals of the CIRP, Vol.44, No.1, pp.333-338, 1995.

[26] Banerjee, S., Ghosal, S. and Dutta, T., Development of a Simple Technique for Improving the Efficacy of Fluid Flow through the Grinding Zone, Journal of Materials Processing Technology, Vol.197, No.1-3, pp.306-313, 2008.

[27] Das, S., Improving Grinding Performance through Appropriate Grinding Fluid Application, Proceedings of the National Conference on Investment Casting, Durgapur, India, pp.97-103, 2003.

[28] Mandal, B., Singh, R., Das, S. and Banerjee, S., Improving Grinding Performance by Controlling Air Flow around a Grinding Wheel, International Journal of Machine Tools and Manufacture, Vol.51, pp.670-676, 2011.

[29] Mandal, B., Singh, R., Das S. and Banerjee, S., Development of a Grinding Fluid Delivery Technique and its Performance Evaluation, Materials and Manufacturing Processes, Vol.27, No.4, pp.436-442, 2012.

[30] Mandal, B., Das, G.C., Das, S. and Banerjee, S., Improving Grinding Fluid Delivery Using Pneumatic Barrier and Compound Nozzle, Production Engineering, 2013, published online [DOI: 10.1007/s11740-013-0507-x].

[31] Mandal, B., Biswas, D., Sarkar, A., Das, S. and Banerjee, S., Grinding Performance Using a Compound Nozzle Characterised by Small Discharge of Fluid, Journal of the Association of Engineers, India, Vol.83, No.1, pp.28-35, 2013.

[32] Mahata, S., Mistri, J., Mandal, B. and Das, S., A Comparative Study of Grinding Performance Using Different Fluid Delivery Techniques, Journal of the Association of Engineers, India, Vol.83, No.3&4, pp.63-70, 2013.

[33] Biswas, D., Sarkar, A., Mandal, B. and Das, S., Exploring Grindability of Titanium Grade 1 Using Silicon Carbide Wheel, Reason- A Technical Magazine, Vol.11, pp.39-46, 2012.

[34] Mandal, B., Biswas, D., Sarkar, A., Das, S. and Banerjee, S., Improving Grindability of Inconel 600 Using Alumina Wheel through Pneumatic Barrier Assisted Fluid Application, Advanced Materials Research, Vol. 622-623, pp. 394-398, 2013.