Research Article

Reason - A Technical Magazine
ISSN 2277-1654
Volume - XI ● 2012

EXPLORING GRINDABILITY OF TITANIUM GRADE 1 USING SILICON CARBIDE WHEEL

Debashis Biswas[1], Anirban Sarkar[2], Bijoy Mandal[3] and Santanu Das[4]

Department of Mechanical Engineering, Kalyani Government Engineering College, Kalyani-741235, India
Email : [1]debashis_bagula@rediffmail.com, [2]aniavit@gmail.com, [3]bijoymandal@gmail.com, [4]sdas.me@gmail.com

Abstract : Titanium and its alloys are being increasingly used in aerospace engineering, corrosive fluid pumps, heat exchangers, sea vehicles, etc. However, it is quite difficult to grind for its high chemical reactivity, high strength, high hardenability and low thermal conductivity causing high grinding temperature, wheel loading, wheel material removal, grit wear, etc. Therefore, selection of wheel, wheel speed and fluid for grinding of titanium is important to achieve desirable surface quality. Formation of a stiff air layer is a major constrain restricting the fluid enter the grinding zone. Optimization of a method of grinding fluid application is essential to control thermal problems from interaction of the wheel grains with the work surface. Adopting an appropriate fluid delivery system may enhance grindability of titanium alloy and can reduce environmental pollution. In the present experimental work, surface roughness, grinding forces and grinding chips are observed under the condition of dry, and wet using a compound nozzle. Surface grinding of titanium Grade 1 alloy is done with the use of silicon carbide wheel. It is found out that grinding under wet with compound nozzle fluid delivery system exhibits fairly good grindability.

Keywords : Surface grinding, compound nozzle, titanium alloy, silicon carbide wheel.

1. Introduction

Unlike grinding of conventional steels where heat generated spreads quickly from high temperature grinding zone, grinding heat gets accumulated during grinding of titanium alloys due to their low thermal conductivity. Strong adhesion of chips on the wheel intergrit spaces is found to be a major cause of poor grindability of alloys of titanium. It increases temperature of the grinding zone, wheel loading, and wheel grit dislodgement as well as requirement of high grinding force and energy. Grinding temperature rises sharply during initial wheel-work contact, attains a quasi-steady state with a long workpiece, and increases further when wheel-work is disengaged [1,2].

Turley [3] observed that loose grinding wheel grits and some chips re-enter the grinding zone and are deposited on the work surface. This creates poor surface finish of ground titanium specimens using alumina wheel. This re-deposition creates progressively increasing surface damage with the increase in hardness of wheel [3,4]. Comparing hard, J grade alumina wheel with soft, H grade silicon carbide wheel, it was observed that the alumina wheel showed poor surface finish due to high adhesion between alumina and titanium. Karyuk [5] reported Ti-alloys to have high strength to weight ratio, excellent corrosion resistance, and ability to make good surface finish, but after grinding, it losses 20-25% of strength from that before grinding. Typical adhesion characteristics of titanium alloy during grinding was observed by Yossofin and Rubenstein [6], while nature of wheel loading in grinding of titanium alloy was reported by Nagraj and Chattopadhyay [7], and mechanism of abrasive wear of titanium and nickel alloys was explored by Xu et al. [8]. Achieving grindability of a titanium alloy with the use of brazed monolayer grinding wheel was also experimentally studied in another investigation [9].

Experimental results obtained by Kumar and Shaw [10] showed that wear of SiC during grinding steels is mainly due to oxidation, whereas wear of Al_2O_3 is primarily due to metal build-up. During grinding of titanium alloy, both types of abrasives result in micro-chipping mode of wearing, and wear rates decrease remarkably with the reduction of wheel speed. Use of cutting fluid is commonly employed to improve wheel life and product surface quality. However, introduction of synthetic cutting fluid often causes environmental and health hazards [4,5,10,11].

It is known that due to the growth of air barrier around the grinding wheel through its high rotation, conventional flood cooling cannot supply fluid in the grinding zone through commonly used nozzles [12,13]. This air barrier has been tried to be suppressed or overcome with the use of rexine pasted wheel [11,14-16], a scraper [11,15], pneumatic barrier [17,18], multi-nozzle [19], etc. Sadeghi et al. [20] proposed an MQL (minimum quantity lubrication) technique which increases significantly the penetrating power of such flow to reach grinding zone due to its small diameter. Wastage of fluid is thereby reduced greatly.

In multi-nozzle system [19], fluid can pass through grinding wheel-workpiece zone easily at low fluid discharge compared to that under normal flood cooling system thereby showing some beneficial effect in grinding. In another experimental work [21] on grinding with compressed ice-cooled air, significant result is obtained to improve grindability of steels with alumina grinding wheel. A cryogrinding technique [22,23] uses a liquid nitrogen jet to improve grinding performance tangibly. However, formation of ice particles under cryogenic temperature causes [11] chocking of the fluid delivery system creating difficulty in grinding. Some of these techniques may also be used for grinding titanium alloys to explore their suitability. In a recent work, Mandal et al. [24] has employed wet grinding with a pneumatic barrier along with alumina wheel, and has obtained certain grindability of titanium grade 1 alloy.

It is already discussed that SiC grinding wheel may be relatively appropriate compared with alumina wheel in grinding exotic materials such as titanium alloys. A silicon carbide grinding wheel is sharper than aluminium oxide, but is more brittle. For favourable properties, silicon carbide wheels are used [3-5] to cut or grind non-ferrous metals like aluminium and cast iron materials. Black silicon carbide is employed for cylindrical, centreless and internal grinding of brass, rubber, cast iron and ceramics, while green silicon carbide is ideally suitable for tungsten carbide tools and also for rolls of chilled iron and glass grinding.

In the present experimental investigation, plunge horizontal spindle surface grinding of titanium alloy is done under dry and wet with compound nozzle conditions with an infeed of 10 µm. Compound nozzle set up is used to facilitate grinding fluid reach deep inside the grinding zone. Thus, grinding temperature would likely be controlled and wastage of fluid may be reduced. The extent of suppression of temperature is judged by observing chips and surface characteristics.

2. Experimental Details

Present experimental investigation is carried out on a surface grinding machine using silicon carbide grinding wheel. Details of the experimental condition are given in Table 1.

Grinding is done in up-grinding mode on titanium Grade 1 alloy in dry and wet conditions. Ten μm infeed and ten number grinding passes are considered for all experiments. Grinding surfaces and chips are observed under a tool makers microscope.

The indigenously made compound nozzle arrangement is shown in Fig.1, where fluid is allowed to pass through three nozzles (each of 1 mm inner diameter). These nozzles are equally spaced within 13 mm of wheel width. Rate of fluid flow for wet grinding is considered to be 1 lit/min. Sushma, Bangalore, India make grinding dynamometer is used for measuring grinding forces.

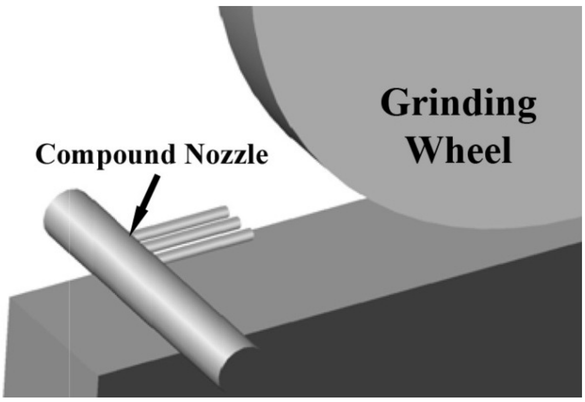

Fig.1 Compound nozzle fluid delivery system

Table 1 Experimental condition

Machine tool used	Surface grinding machine Make : Maneklal & Sons, Kolkata, India Infeed resolution : 10 μm Main motor power : 1.5 kW
Grinding wheel	Disc type silicon carbide wheel Make : Carborandum Universal Limited, India Specification : GC60K5VC7, Size: ø180 mm × 13 mm × ø31.75 mm
Grinding conditions	Wheel velocity : 30 m/s Grinding fluid flow rate : 1 lit/min Infeed : 10 μm Table feed : 7.5 m/min Number of passes : 9
Workpiece material	Titanium Grade 1 (99.85% Ti, 0.01% N, 0.12% Fe, 0.02% O) Hardness : 220 HB
Workpiece size	120 mm x 65 mm x 6 mm

3. Experimental Results and Discussion

Tangential (Ft) and normal (Fn) grinding forces are measured during grinding of titanium Grade 1 alloy at 10 μm infeed under dry and wet conditions. Variation of both grinding forces (Ft and Fn) with number of grinding passes are represented in Fig.2. It is observed that both Ft and Fn have an increasing trend with the progress of grinding passes in both dry and wet conditions. At dry grinding environment, Fn increases up to 5 passes. After 7th grinding pass, both Ft and Fn are highly increased, possibly due to intense wheel loading as observed after the 7th pass of grinding, and grit wearing in this situation. At the 9th grinding pass, Fn (187.4 N) and Ft (36.3 N) are quite high with compared to Fn (74.6 N) and Ft (24.5 N) of wet condition. High values of Ft and Fn under dry grinding indicate unsuitable condition for grinding.

Grinding chips are collected after 8th grinding pass, and observed under Tool Maker's Microscope. Microscopic views of grinding chips, under dry and wet conditions, are shown in Fig.3 and Fig.4. Most of the chips obtained during dry grinding are short segmented and slice type (Fig.3). Along with chips, wheel grit materials are also observed. This indicates that grinding wheel is highly loaded during dry grinding. Under wet grinding condition, most of the chips (Fig.4) are shear type (curled chip). This indicates that in wet grinding, due to lubrication and cooling action, wheel grits may have retained its sharpness better than dry grinding.

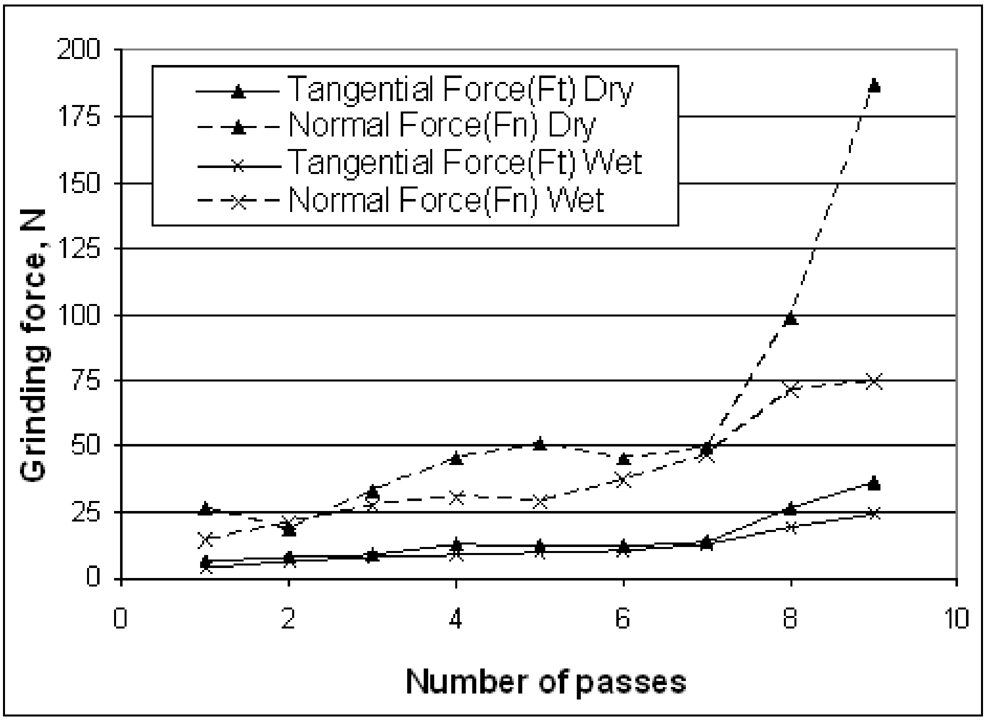

Fig.2 Variation of grinding forces with number of grinding passes under dry and wet conditions at 10 µm infeed

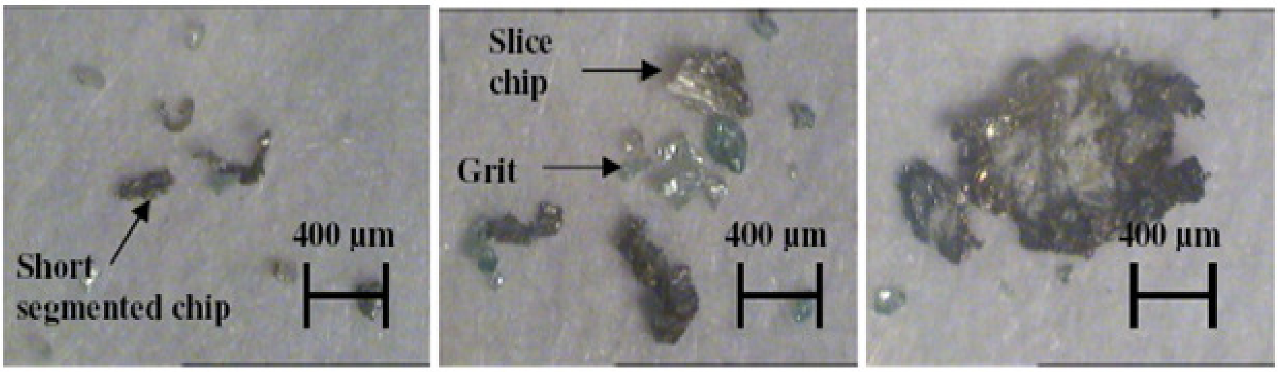

Fig.3 View of grinding chips under dry condition at 10 µm infeed

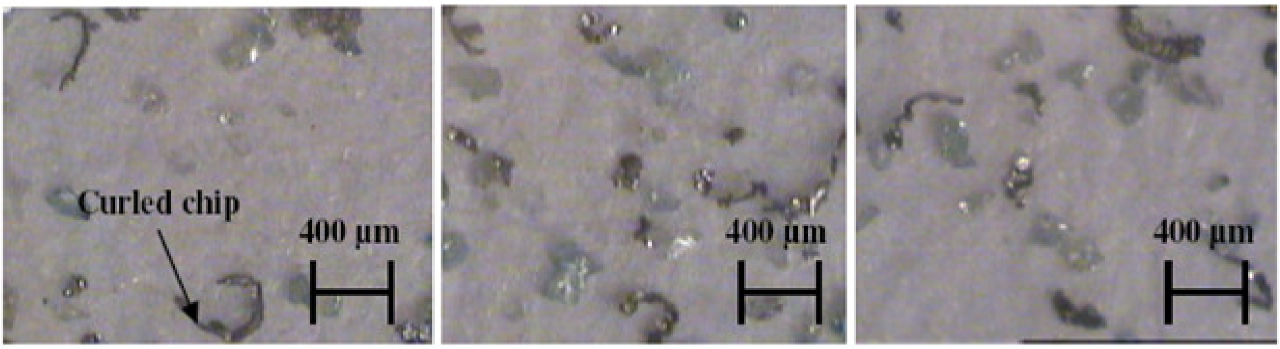

Fig.4 View of grinding chips under wet condition at 10 µm infeed

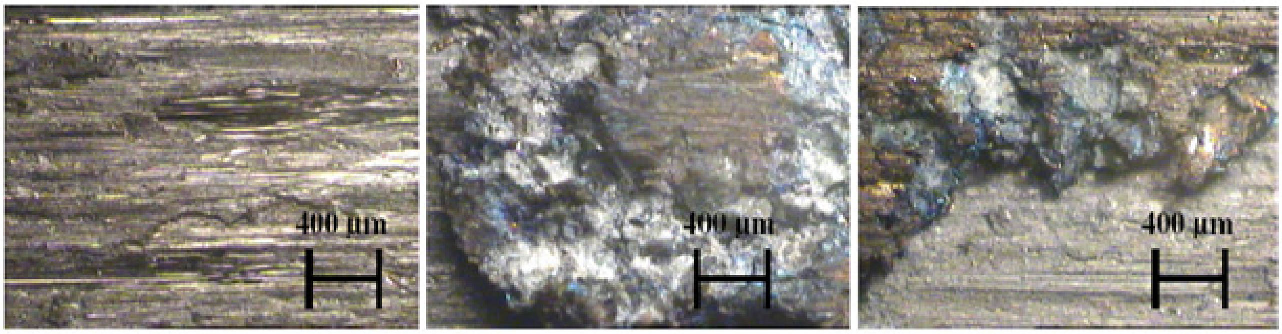

Fig.5 View of ground surfaces after nine passes at 10 µm infeed under dry condition

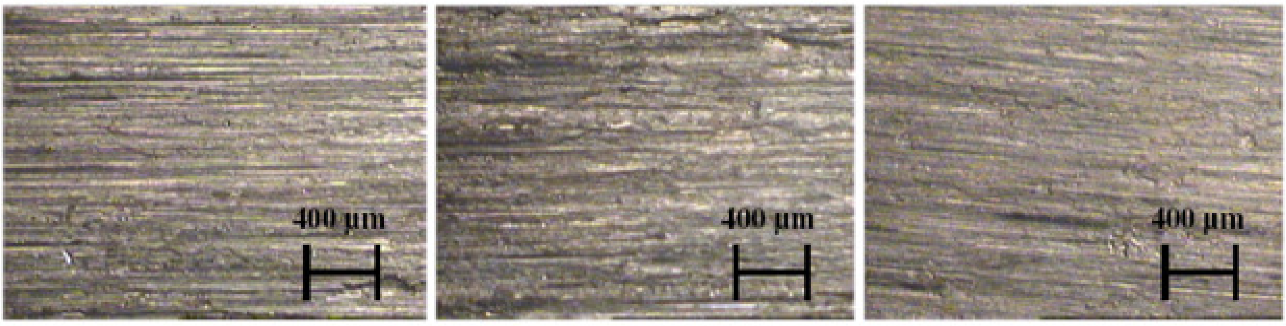

Fig.6 View of ground surfaces after nine passes at 10 µm infeed under wet condition

Views of ground surface are taken at three different places of the workpiece after 9 grinding passes under both dry and wet conditions as shown in Fig.5 and Fig.6.

In dry grinding, the surface is poor and some portions are melted and deformed (Fig.5). High vibration is also experienced during 9th pass of grinding. This indicates that the grinding wheel is highly loaded and glazed at this condition that is also visually observed during experimentation, resulting in generation of high temperature at grinding zone.

In wet grinding, no surface burning is observed, and comparatively better surface is generated than dry grinding. This shows that wet grinding using compound nozzle can effectively control grinding zone temperature at this condition. However, when number of grinding passes are increased beyond 9 passes, poor grindability of titanium Grade 1 alloy is observed, thereby limiting the allowable grinding passes up to nine under the multi-nozzle cooling system within the domain of these experiments.

4. Conclusions

Following conclusions may be drawn from the present experimental investigation.

- ➢ In dry condition, grinding forces increase abruptly after 7 grinding passes indicating high wheel loading and glazing. Grinding forces are lower on the whole in wet grinding due to better lubrication and cooling action of grinding fluid.
- ➢ Large amount of short segmented chips and chunk of workpiece material indicate high wheel loading and poor grinding performance in dry grinding. Highly burnt and melted work surface is indicating that selected silicon carbide wheel is not suitable for grinding of Titanium Grade 1 alloy under dry condition. However, some favourable chips and ground surface are obtained in wet grinding using compound nozzle fluid delivery system, and, hence, it may be employed for grinding this titanium alloy.

References

[1] Malkin, S. and Guo, C., Thermal Analysis of Grinding, Annals of the CIRP, Vol.56, No.2, pp.760-782, 2007.

[2] Malkin, S. and Anderson, R.B., Thermal Aspects of Grinding, Part-I, Energy Partition, Transactions of the ASME, Journal of Engineering for Industry, Vol.94, pp.1177-1183, 1974.

[3] Turley, D.M., Factors Affecting Surface Finish when Grinding Titanium and Titanium Alloy (Ti-6Al-4V) Materials, Research Laboratories, Defence Science and Technology Organization, Australia, Vol.104, No.4, pp.223-235, 1985.

[4] Li, Y., Rowe, W.B. and Mills, B., Grinding Conditions and Selection Strategy, Journal of Engineering Manufacture, Vol.213, No.2, pp.119-129,1999.

[5] Karyuk. G.G., Effect of Grinding on the Structure of the Ti-alloys. Institute of Material Science, Ukrain, SSR, Vol.192, No.12, pp.69-75, 1978.

[6] Yossifon, S. and Rubenstein, C., The Grinding of Workpieces Exhibiting High Adhesion, Part 1: Mechanisms, Transactions of the ASME, Journal of Engineering for Industry, Vol.103, pp.144-155, 1981.

[7] Nagaraj, A.P. and Chattopadhyay, A.K., On Some Aspects of Wheel Loading, Wear, Vol.135, pp.41-52, 1989.

[8] Xu, X., Yu, Y. and Huang, H., Mechanisms of Abrasive Wear in the Grinding of Titanium (TC4) and Nickel (K417) Alloys, Wear, Vol. 255, pp.1421-1426, 2003.

[9] Teicher, U., Ghosh, A., Chattopadhyay, A.B. and Kunanz, K., On the Grindability of Titanium Alloy, by Brazed Type Monolayered Superabrasive Grinding Wheels, International Journal of Machine Tools and Manufacture, Vol.46, pp.620-622, 2006.

[10] Kumar, K.V. and Shaw. M.C., Metal Transfer and Wear in Fine Grinding, Wear, Vol.82, No.2, pp.257-270, 1982.

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

[12] Mandal, B., Majumder, 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.654-659, 2010.

[13] Rodrigo, E.C., Eduardo, C.B., Felipe, M.Z. and Paulo, R.A., Global Analysis of Aerodynamics Deflectors Efficiency in the Grinding Process, Journal of the Brazilean Society of Mechanical Science and Engineering. Vol.28, No.2, pp.140-146, 2006.

[14] 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.

[15] 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, XVI National Convention of Production Engineers, Varanasi, India, pp. 182-187, 2002.

[16] Mandal, B., Majumder, 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.

[17] 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, pp.436-442, 2012.

[18] 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, No.9, pp.670-676, 2011.

[19] Mandal, B., Das, G.C. and Das, S., Development of a Simple Technique for Controlling Wastage of Grinding Fluid, Proceeding of the 17th West Bengal State Science and Technology Congress, Kolkata, India, p.68, 2010.

[20] Sadeghi, M.H., Haddad, M.J., Towakoli, I. and Emamim M., MQL Grinding Technique, International Journal of Advanced Manufacturing Technology, Vol.44, No.5-6, pp.487-500, 2009.

[21] Dewanjee, D., Kundu, P., Sikder, B., Biswas, D., Mandal, B. And Das, S.,

Improving Grinding Performance with the Use of Grinding Fluid Leading to Green Manufacturing, Proceedings of the International Conference on Mechanical Engineering 2011, Dhaka, Bangladesh, pp.RT031-RT036, 2011.

[22] Paul, S., Das, S., Bandyopadhyay, P.P. and Chattopadhyay, A.B., Effects of Cryogenic Cooling on Wheel Loading in Grinding Steels, Proceedings of the 16th AIMTDR Conference, Bangalore, India, pp.478-484, 1994.

[23] Paul, S. and Chattopadhyay, A.B., A Study of Effects of Cryogenic Cooling in Grinding, International Journal of Machine Tools and Manufacture, Vol.35, No.1, pp.109-117, 1995.

[24] Mandal, B., Biswas, D., Sarkar, A., Das, S. and Banerjee, S., Improving Grinding Performance through Appropriate Grinding Fluid Application, Experimental Observation on Grindability of Titanium Gr.1 Under Different Environment, Proceedings of the 4th International and 25th AIMTDR Conference, Jadavpur, Kolkata, India, pp.357-362, 2012.