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APPLICATION OF SOLID LUBRICANTS IN GRINDING: AN INVESTIGATION ON GRAPHITE MOLDED GRINDING WHEELS

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ABSTRACT

Cooling and lubrication play a decisive role in grinding tribology. The intense heat generated during the process, if not controlled, will lead to major quality defects in grinding. Conventional liquid coolants, employed in flood form, have many limitations from technical, environmental and economic angles. Minimization or possible elimination of cutting fluids by substituting their functions by some other means is emerging as a thrust area of research in grinding. The application of solid lubricants in grinding has proved to be a feasible alternative in this direction, if it could be applied in a proper way. Towards finding out an improved method of application of solid lubricant, attempts on development of solid lubricant moulded grinding wheels with graphite as lubricant have been reported here. Such wheels with resin bonding were successfully made and improved process results were obtained.

Keywords : Grinding, lubrication, graphite

1. INTRODUCTION

The intense heat generation involved in the grinding process, due to high specific energy and high wheel-workpiece friction, is critical to the product quality. Cooling and lubrication therefore play a decisive role in grinding tribology [1]. Conventional liquid coolants employed in flood form are ineffective due to the ‘air barrier’ and ‘film boiling’ effects [1,2]. Further, grinding fluids cannot be recommended in the light of ecological and economic manufacture [3,4]. Minimization or possible elimination of grinding fluids by substituting their functions by some other means is emerging as a thrust area of research in grinding. The use of bio-degradable and cryo-coolants, the concept of minimum quantity lubrication (MQL) etc. are the alternative techniques, recently attempted, in this direction [1,5].

Towards finding out an alternative approach for replacing the grinding fluid, an attempt to reduce the heat at its generation stage itself would be ideal rather than removing the heat after its generation. The advancement in the modern tribology has identified many solid lubricants, which can sustain and provide lubricity over a wider range of temperatures [6,7]. If solid lubricant can be successfully applied to the grinding zone in a proper way, as a means to reduce the heat generated due to friction, it should yield better process results. Authors have established the feasibility of this concept with graphite as lubricant, by applying it in a suitable paste form on the working surface of the wheel during grinding, with the aid of an experimental set-up [8]. In this study, the effective role of graphite as lubricant was evident from the improvement of process results related to frictional factors. But wheel clogging, in the absence of proper flushing, was found to be a major hindrance in yielding better process results. Towards an attempt to apply solid lubricant in a more defined are refined way, graphite molded wheels were developed, by including graphite as an ingredient in the molding stage. This paper deals with the development of such wheels and their experimentation.

2. DEVELOPMENT OF WHEELS

2.1 Trials with Vitrified Bonded Wheels

Majority of grinding wheels used in general engineering industry are of vitrified bond. Vitrified bond is made of clay or feldspar, which fuses at high temperature to form a glass like structure. They are strong, rigid, impart good finish and insensitive to water or other grinding fluids. While making the wheel, the ingredients such as abrasive grains, bonding material, porosity media, water etc. are uniformly mixed and properly molded. These green wheels are baked at very high temperature for long duration, followed by slow cooling [9,10,11]. Several trials were done to make graphite molded vitrified bonded wheels with A60K5 wheel composition by mixing graphite powder along with the usual ingredients, during the molding stage. But this attempt failed. The vitrifying temperature is of the order of 1400°C. Graphite starts oxidation at about

550°C. If the firing is done in the presence of oxygen, graphite will decompose, loosing its lubricative property and the resulting products would affect the bonding strength of the wheel. Due to the non-availability of a reduction furnace, attempts to vitrify the graphite molded wheels were done by embedding the lubricant molded green wheels in graphite mass itself with sufficient packing thickness such that the oxidation effect would not affect the wheel. But the wheels produced were having differential colors, showing the occurrence of oxidation. These wheels could not withstand the speed testing at the standard ratings.

2.2. Trials with Resin Bonded Wheels

Resin bonded wheels are manufactured in a similar manner as the vitrified wheels, but the bonding medium is thermosetting synthetic resin and the baking temperature is of the order of 150-200°C only. These wheels are soft structured and are used for high speed grindings, rough grindings, cutting-off operations etc. The wheel wear rate is high and wheel softens when exposed to grinding fluids [9,10,11]. The low baking temperature involved in resin bonding prompted the trials with solid lubricants included in the wheel structure during molding. CUMI's A60L5BM4 (250-76.2-25 mm size) wheel was taken as the standard wheel. This wheel consists of ingredients of 91% abrasive grain and 9% bonding material by weight. Three graphite molded wheels were made by adding graphite in 3%, 6% and 9% by weight to the standard wheel ingredients. All the wheels withstood speed testing at standard conditions.

3. EXPERIMENTATION

The experimentation was done in a horizontal surface grinding machine. In any machining set-up, a systematic analysis of process parameters is essential to find out their relative influence on the direct process outputs. Therefore, the most influential factors were identified by conducting a 3-level 4-factor (speed, feed, infeed and mode of dressing) experiment following the Taguchi's L_9 orthogonal array with 4 repetitions, taking force components and surface finish as quality characteristics. ANOVA based on S/N data showed infeed as the most influential factor on both normal and tangential forces (about 85%). In the case of surface finish, though the mode of dressing was found to have a prominent influence, its relative contribution was substantially less (about 40%), when compared to that with vitrified wheels (about 75%) [12].

Based on the above findings on the influence of process parameters, experiments for the performance analysis of the newly developed wheels were done in one dressing mode only, varying the infeed in steps. The experimental conditions are shown in Table 1. The factors selected for the study are force components, force ratio, specific energy, surface roughness, wheel wear and intermittent forces in continuous test. For force measurements, a 3- component quartz dynamometer (Kistler-type 9257b) with charge amplifier (Kistler-type 5019b) and a 2-channel oscilloscope connected directly to a PC were employed. The forces reported are those when the process was in stable state with almost steady pulses. Surface roughness (*Ra*) of the ground part was taken using a Talysurf.

Table 1 Experimental conditions

Machine: BLOHM Horizontal spindle surface grinding machine, 6.5 kW
Wheel: 1.Standard: A60L5BM4, (CUMI)
2. Graphite molded wheels with 3%, 6% and 9% graphite by weight included in the wheel
(All wheels are of 250-76.2-25 mm size)
Workpiece Bearing steel (En-31), HRC 60
Cutting speed : 42 m/s
Feed : 10 m/min
Infeed : 10 to 80 µm in steps of 10 µm
Method of grinding:: Dry
Dressing conditions: With single point diamond dresser, 1 carat, at wheel speed of 2500 rpm in dry condition with 20µm dressing depth,~ 150 mm/min cross feed and without any spark out pass.

4. RESULTS AND DISCUSSION

Figures 1 and 2 show the comparisons of normal and tangential force components obtained (per unit width of the wheel) when grinding was done with different wheels. Grinding forces are important parameters by which performance of any grinding process can be evaluated. These forces are based on different elements, which largely depend on the wheel characteristics, work material characteristics, process parameters, nature of wheel-workpiece interaction and the chosen environment. In all the cases under study, force components increased with infeed as expected. This agrees with the various physical and empirical models reported, which mention that force components are directly proportional to the mean undeformed chip thickness, which in turn is directly proportional to the infeed [13, 14].

Normal force component influences all the parameters pertaining to the performance of a grinding wheel. This force presses the abrasive grains into the work surface and penetrates the surface, leading to material removal. At higher infeeds, the normal force increases causing more material removal. Wheel clogging by grinding swarf also causes an increase in the normal force, by hindering the effective penetration of grains into the work surface. The normal forces obtained were lower with

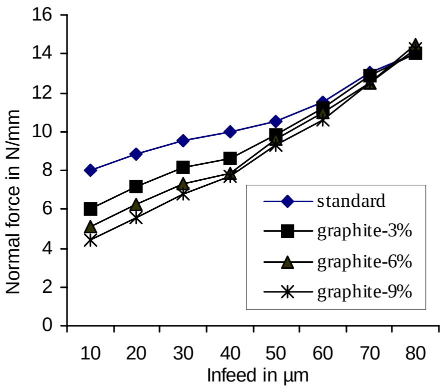

Fig 1 Normal force obtained with various wheels

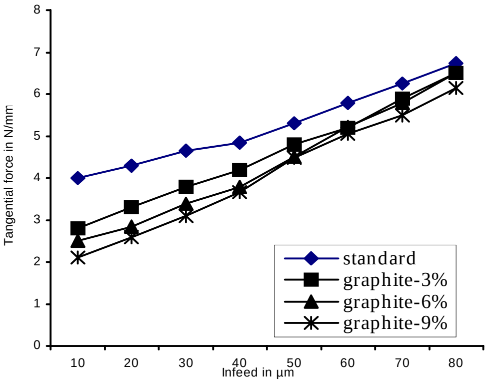

Fig. 2 Tangential force obtained with various wheels

the graphite-moulded wheels compared to the standard wheel, as the frictional effects were reduced due to the effective lubrication by graphite. In the earlier study on the external application of lubricant with vitrified wheels, the normal forces obtained in some cases were higher than those in normal grinding, due to the non-uniform supply of lubricant and increased chances of wheel clogging [8]. But here, an efficient way of lubricant supply, which minimized wheel clogging by grinding swarf, might reduce the normal force to some extent. As the wear rate is higher with resin wheels, fresh grains might also more frequently come into contact with the workpiece on subsequent passes, preventing the increase of forces due to grain dullness.

The tangential force component determines the intensity of heat generation in the process and is primarily important as far as the grinding temperatures and surface integrity aspects of the products are concerned. The lubricant effectiveness in minimizing the frictional effects at the wheel-workpiece interaction in the case of graphite-moulded wheels is evident from the reduced tangential forces compared to the standard wheel.

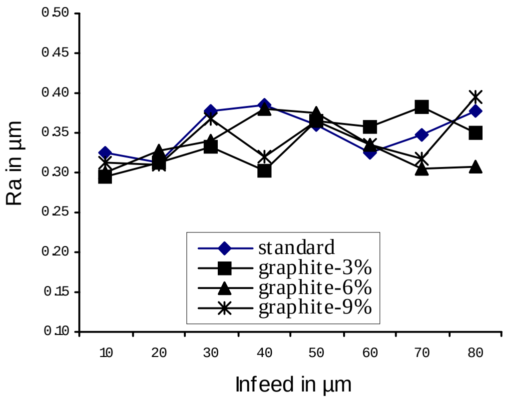

Fig.3 Force ratio obtained with various wheels

The ratio of tangential force to normal force (F_t/F_n) is termed grinding coefficient [15] or grinding force ratio [13,14] This force ratio, though it does not give the actual coefficient of friction (μ), is a similar term like μ and gives an indication of the frictional effects in the grinding zone [15]. Figure 3 shows the comparison of grinding force ratio obtained with different wheels. This ratio is generally lower in all the cases of graphite-moulded wheels, compared to the standard wheel, substantiating the effective lubrication by graphite in those cases.

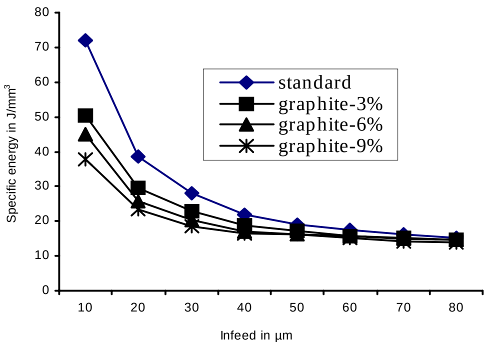

Fig 4. Specific energy obtained with various wheels

Figure 4 shows the variation of specific energy requirements under various situations of grinding. Specific energy increases with a decrease of infeed in all conditions of grinding under study. This established behaviour, termed as size effect, is due to the domination of sliding and ploughing components at lower infeeds [9]. Moreover, the chip formation process in fine grinding is a special high strain extrusion process that involves rapidly increasing strain rate with a decrease of the undeformed chip thickness at lower infeeds [11]. Specific energy requirement is substantially lower in all the cases of graphite-moulded wheels.

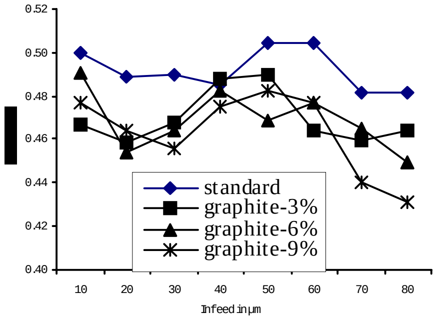

Fig 5. Surface roughness obtained with various wheels

Figure 5 shows the comparisons of workpiece surface roughness. Surface topography of the wheel determines the nature of the tribological interaction between the wheel and workpiece. Workpiece. Surface roughness is the minute scratches formed by the interacting wheel surface under the dynamic conditions of the process. The surface roughness scatter is not wider for various types of wheels. This is due to the fact that for a particular wheel, surface condition of the wheel is more or less the same for all conditions of infeed, due to the increased wear of the resin bonding. The wheel lost its dressed surface condition immediately after the initial passes.

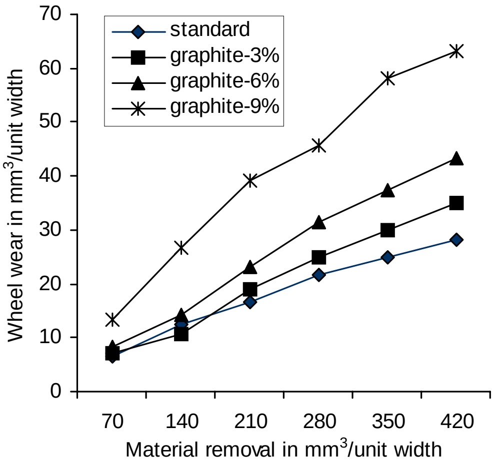

Fig 6. Wheel wear obtained with various wheels

Figure 6 shows wear obtained with different wheels. The wear of graphite-moulded wheels is higher, when compared to the standard wheel. The presence of graphite may weaken the bonding, leading to higher wear. The wheel wear increases with higher quantities of graphite inclusion. The solid lubricants, which have a fusion bonding nature at high temperature, such as CaF_2, might result less wear of the wheel [16].

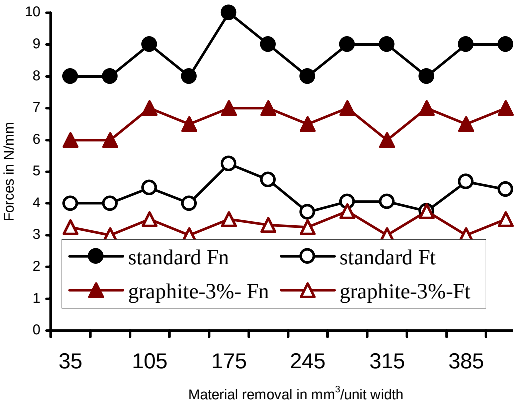

Fig 7. Intermittent forces obtained in continuous grinding test

Figure 7 shows the force pattern obtained from intermittent measurements during continuous grinding test. The test was done by giving 10 µm infeed for every upgrinding pass. Forces were measured in every 25th pass. The force values are more or less the same through out the test. This is in contrast to the case with vitrified wheels, wherein forces were increasing to certain extent in continuous test [15]. As the wheel wear rate is higher with resin wheels, during continuous grinding, fresh grains might frequently come into interaction. But with vitrified wheels, where the wheel wear is dominated by the mechanical fracture, load on the wheel increases till the critical force required for the friability of grains occurs. In this test also, the force components of graphite-moulded wheels were found to be lower than that of the standard wheel through out the grinding

5. CONCLUSION

As an alternative way to extract the advantages of solid lubricant application in grinding through out the usage of wheel, solid lubricant molded resin wheels were developed with graphite, by including graphite as an ingredient during the moulding stage of the wheel. Trials to make such wheels with vitrified bonding failed due to higher vitrifying temperature and non-availability of a good reduction furnace for firing. In the case of graphite-molded wheels, the effectiveness of graphite as lubricant was evident from the improved process results related to friction. But, the wheel wear was found higher with such wheels, compared to the standard wheel.

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