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GRINDING BURNS IN A PROCESS OF HIGH SPEED DEEP GRINDING

Formulated the problem of the need to develop new equipment and processing technology by deep sanding flat surfaces and flat shaped parts of aircraft engines of difficult to cut materials. A study was conducted to apply state - direct equipment for creep feed grinding. The recommendations on the use of new equipment for the processing of flat and shaped surfaces flat components of aircraft motors using different kinds of grinding wheels and lubricate coolant , compelling stakeholders to more efficiently and with less labor to machine difficult to cut materials for aircraft and motor building.

Key words: *deep grinding, technological process, the planetary deep grinding, economic effect, difficult to machine materials.*

Introduction

With the increasing requirements of modern aerospace engineering and technology and high-performance technological products in respect of part precision, surface integrity, machining efficiency and batch-quality stability, grinding has played a more and more important role. It becomes an important part of advanced machining technology and equipment, and is a research frontier in manufacturing science.

Generally, the wheel velocity between 30 and 35 m/s is defined as conventional grinding; The wheel speed exceeding 45 to 50 m/s is defined as high speed grinding; The wheel speed between 150 and 180 m/s or higher is defined as Super-high Speed Grinding. The specific material removal rate in conventional grinding is less than 10 $mm^3/mm\cdot s$. It has long been a pursuit in academe and engineering field to improve grinding efficiency. There are three approaches:

1) adopting high-speed, super-high speed or wide-wheel grinding to increase the amount of active abrasive per unit time;

2) increasing cutting depth so as to increase the length of grinding debris;

3) adopting powerful grinding to in-crease the mean cross-sectional area of grinding debris.

Any grinding techniques adopting single or multiple methods mentioned above to improve specific material removal rate in comparison with conventional grinding can be called as high-efficiency grinding techniques. Among them, the development of high-speed/super-high speed grinding, creep-feed deep-cutting grinding, high-efficiency deep-cutting grinding, belt grinding and heavy-duty snagging has drawn most of the attentions.

1. Problem statement

Grinding is a process typically used for finishing process. Machining process without undergo finishing process cannot achieve high enough dimensional accuracy and/or good quality finish. Grinding is a process to maintain quality, but in the way around, doing some mistakes will be affect directly to cost of operation.

Problem always occur during grinding process is work piece burning. It is contribution from the excessive temperature of the workpiece during grinding. These phenomenon is an obstacle to obtain desired surface finish and also dimensional accuracy.

The selection of abrasives and process variables, including condition of grinding, is important in order to obtain the desired dimensional accuracy and surface finish. Otherwise, workpiece surface is damaged such as burning.

Grinding process is one important process for finishing. It is important to know the finishing operation available for improve surface finish. This is because it might contribute significantly to the operation cost.

2. Problem solving

2.1. Depth of Cut.

Depth of cut (d) is the distance of the grinding wheel penetrates into the workpiece. The depth of cut affects to the processing speed. When the cutting depth is big, the processing speed becomes quick and the surface temperature becomes high. The surface roughness of the workpiece will be change. Moreover, a life of bite also becomes short. If suitable cutting depth is unknown, it better to start machining with small cutting depth (Kwak J.S., 2004 and Merchant M.E., 1994).

2.2. Worktable Speed.

Worktable speed is the speed of the worktable movements. The workpiece will be stick by magnetic worktable of the grinding machine. The speed of the worktable will be influence the rate of the grinding for the workpiece. The worktable speed can measure by using the tachometer for the conventional surface grinding machine. By change the worktable speed applied, the surface roughness of the workpiece also will be change (Kwak J.S., 2004 and Merchant M.E., 1994).

2.3. Types of Wheel.

Types of wheel for the grinding process will be chosen depends on the material that will be use for the workpiece. If the material use for grinding process have high hardness, so the grinding wheel that will be use also have high hardness point. The suitable grinding wheel use for the grinding process is important to avoid the wheel and workpiece from broken. The ability of the wheel depends on its grit number. Larger grit number of the wheel will produce more fine surface finish (Kwak J.S., 2004 and Merchant M.E., 1994).

2.4. Grinding Wheel (cubic boron nitride).

Diamond though hardest is not suitable for grinding ferrous materials because of its reactivity. In contrast, CBN the second hardest material, because of its chemical stability is the abrasive material of choice for efficient grinding of HSS, alloy steels, HSTR alloys. Presently CBN grits are available as monocrystalline type with medium strength and blocky monocrystals with much higher strength. Medium strength crystals are more friable and used in resin bond for those applications where grinding force is not so high. High strength crystals are used with vitrified, electroplated or brazed bond where large grinding force is expected. Microcrystalline CBN is known for its highest toughness and auto sharpening character and found to be best candidate for HEDG and abrasive milling. It can be used in all types of bond.

2.5. The Application of Grinding Fluid.

In grinding, grinding fluids perform a number of functions within the process. Figure 1, presented by Brinksmeier et al. (1999) demonstrates the primary effects of lubrication and cooling in the machining process, further to this however it is commonly accepted that coolant also assists in the removal of grinding chips from both the grinding wheel and grinding zone.

2.6. Grinding Burn.

Surface integrity is described by Field & Kahles (1971) as the study and control of both surface roughness and surface metallurgy. They comment that conditions for developing surface integrity need not be imposed unless the service requirements dictate. When considering stock removal processes the issue of surface integrity is of lesser importance, particularly the generated surface roughness as subsequent finishing passes of the grinding wheel at more conventional rates can remove undesirable surface effects. The depth of a surface effect is therefore critical if it is to be successfully removed. This is particularly significant in the HEDG regime where very high temperatures are generated during the process.

Grinding burn makes broad reference to the effects of temperature on the surface integrity of the workpiece to rehardening burn. Badger & Torrance (2000) demonstrate schematically the varying levels of burn experienced against a relative temperature profile (figure 2) the onset of oxidation burn occurring at relatively low temperatures. The authors consider oxidation burn to be largely cosmetic; however it is clear that the presence of oxidation burn may imply a deeper level of damage.

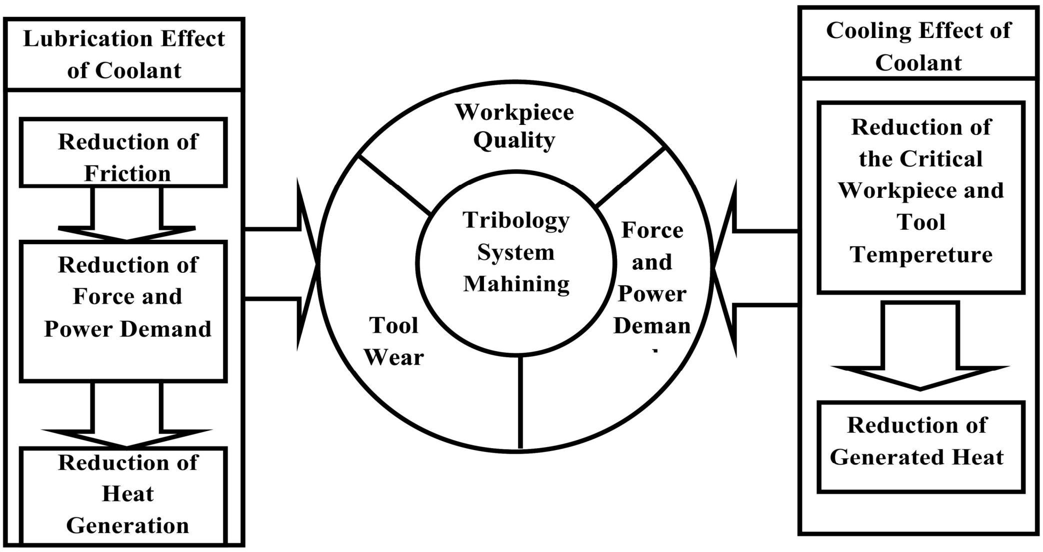

Fig. 1. Primary effects of lubrication and cooling in the machining process after Brinksmeier et al. (1999)

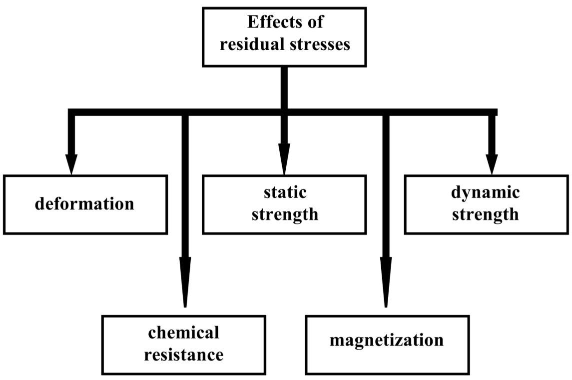

Fig. 2. Primary effects of residual stress after Brinksmeier et al. (1982)

The importance of damage resulting from the grinding process, grinding burn, cannot be underestimated. Field & Kahles (1971) comment on the importance of dynamic loading as a principal factor for engineering design, where fatigue life failures initiate on the surface. Further it is suggested that the surface condition is a primary factor in stress corrosion problems. The author demonstrates the effect of grinding on the fatigue life for three commonly employed engineering materials, summarized in table 1, and highlights significant reduction in fatigue life with abusive grinding conditions. The detrimental effect of a poorly controlled grinding process is qualified by Silva (2003) describing the failure of a vehicle crankshaft due to thermal fatigue cracking, Whilst Eliaz et al. (2005) described the discovery of a crack in the main landing gear of a cargo aircraft as a result of abusive grinding. Whilst both events will result in a significant financial impact for the manufacturer, the failure described by Eliaz et al. (2005) is of particular importance as landing gear are a safety critical element of the aircraft. Their failure could have fatal implications. Brinksmeier et al. (1982) demonstrate schematically the primary effects of residual stresses (figure 3). They consider the residual stresses to be the result of combined thermal and mechanical effects also discussed by Mahdi and Zhang (1999a & b) and Snoeys et al. (1978). Further, consideration of residual stress as the result of phase transformation is presented by Brinksmeier et al. (1982) Mahdi & Zhang (1999b) and Snoeys et al. (1978). Brinksmeier et al. (1982) consider some of the elements which result in a residual stress in the surface including machining conditions, wheel wear behavior and the type and construction of the wheel.

Of the forms of grinding burn commonly encountered, tensile residual stress is considered to be the most significant. The presence of tensile residual stress will promote fatigue failures, crack initiation and crack propagation. Chen et al. (2000) describe the origins of residual stress as the result of three effects during the grinding process; thermal expansion and contraction, phase transformations when high temperatures are encountered and plastic deformation due to the abrasive grains of the wheel. They suggest that the most significant element in the generation of residual stress is the effect of thermal expansion and contraction and that this allows the process of predicting residual stress to be simplified to the prediction of temperature of CBN wheels on residual stress in the as ground surface.

allows the process of predicting residual stress to be simplified to the prediction of temperature of CBN wheels on residual stress in the as ground surface after Althaus (1982) cited Brinksmeier et al. (1982)

The focusing of the grinding burn problem on the generation of residual stress allows for the application of several commonly available technologies for burn detection.

The effect of residual stress condition on hardness measurements has been demonstrated in the literature. Frankel et al. (1993) show an example of auto fretted cylinders exhibiting a compressive internal diameter and a tensile outside diameter. Using Rockwell C hardness measurements, the authors show a decreasing hardness value with increasing tensile residual stress. This effect is also seen in the work of Blain (1957) in which Rockwell C measurements of surface hardness were seen to be similarly reduced by the presence of a tensile residual stress. The use of surface hardness as an indicator of a residual stress profile should be easily established and with the use of nondestructive ultrasonic contact impedance equipment can be tested.

Table 1

Effect of grinding processes on fatigue life of common engineering materials after Field & Kahles

Alloy	Machining Operation	Endurance Limit in Bending 10^7 Cycles (psi)
4340 Steel, 50 R_c	Gentle grinding	102,000
	Abusive grinding	62,000
Titanium 6Al-4V 32 R_c	Gentle grinding	62,000
	Abusive grinding	13,000
Inconel 718, Aged, 44 R_c	Gentle grinding	60,000
	Conventional Grinding	24,000

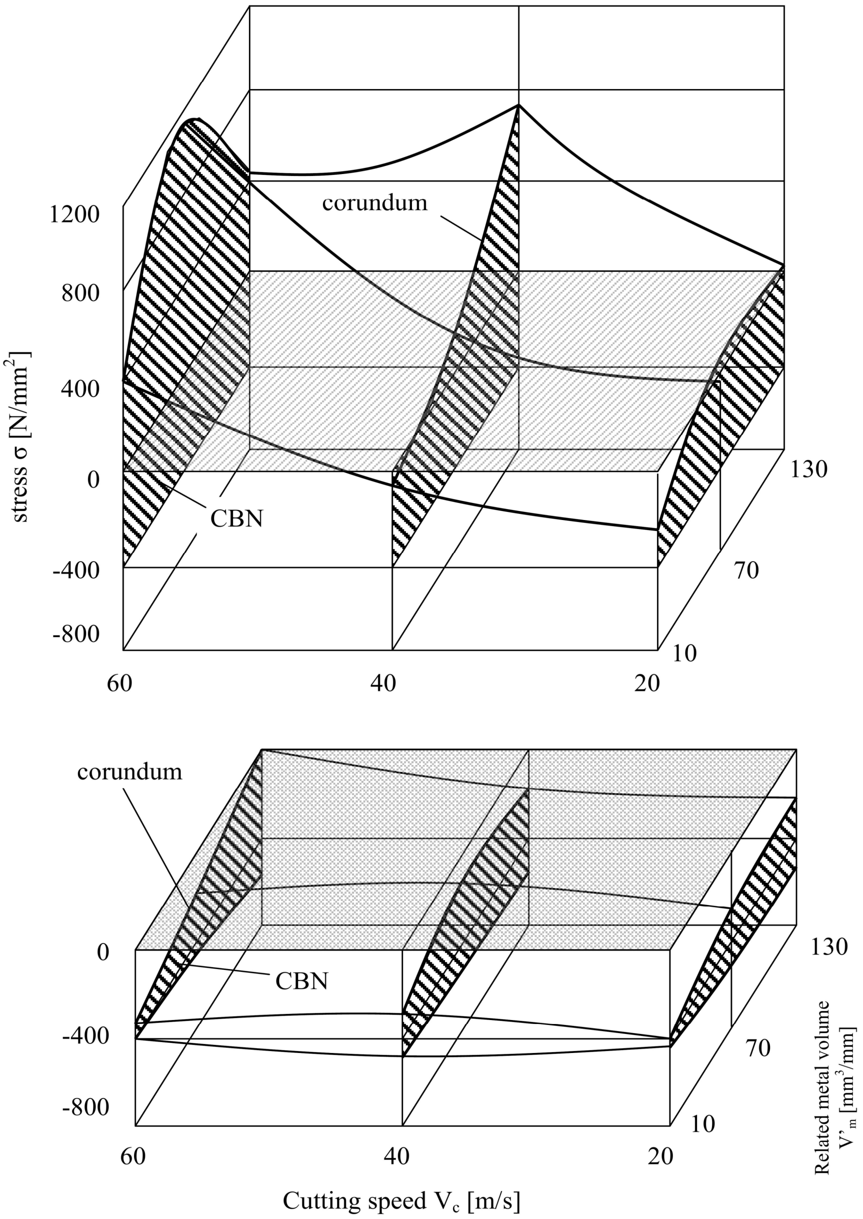

Fig. 3. Effects of oil as a grinding fluid

Shaw et al. (1998) and Desvaux et al. (1999) show good results for the detection of grinding burn with Barkhausen noise analysis. Both sets of authors comment on the usability of the process, with Desvaux et al. (1999) commenting on its value as a replacement for the existing x-ray diffraction technique, which is considered lengthy, expensive and relatively inflexible for a more complex geometry. The authors agree that the Barkhausen technique demonstrates a correlation to the residual stress condition; however it is highlighted by Shaw et al. (1998) that the results require quantification against actual material properties developed. More recently, Comley (2005) utilized the Barkhausen technique for the detection of grinding burn, concluding that the set-up, whilst comparative, provides a quick non-destructive method suitable for industrial application.

The appearance of oxidation burn, i.e. the presence of temper colours on the workpiece surface has been used by Johnstone (2002) as a simple method of detecting grinding burn. McCormack et al. (2001) consider the use of temper colours for determination of grinding burn claiming that temperatures at which oxidation occurs are increased as a result of the unusually short thermal pulse time in grinding. They consider the presence of surface oxidation in a critical component to be completely unacceptable due to the risk of sub-surface metallurgical damage, although comment on its acceptability on non-critical surfaces where it may be polished out.

2.7. Temperature Measurement.

The measurement of temperature in any manufacturing process is complicated by issues of accessibility to and the dynamics of the process in question. When considering machining processes, the accurate measurement of temperature is further frustrated by the addition of lubrication to and the removal of swarf from the cutting zone. This is of particular concern for the grinding process, which in many cases floods the wheel workpiece interface with coolant as in the creep feed grinding process or produces high volumes of waste material as found in stock removal processes.

The use of thermocouples for temperature measurement in grinding is commonplace. Several examples are available of literature presenting results developed from the process, for example temperature measurements in Rowe et al. (1998) and Rowe & Jin (2001) utilised this method for verification of thermal models of HEDG. Tawakoli (1993) presents an example of the use of thermocouples for the development of surface temperatures in grinding regimes. He describe temperature range and the ability to place them in or just below the contact zone via drilled holes. It is also noted that the thermocouples require a reference temperature for set-up. The author provides a schematic figure 4. Of a thermocouple technique for extrapolating surface temperatures via a series of thermocouples placed at varying depths from the contact surface.

2.8. High efficiency deep grinding.

The High Efficiency Deep Grinding (HEDG) regime is the result of the development of wheel and machine technologies capable of delivering both high wheel and workpiece feed rates with a large depth of cut. The process is the product of the high speed and creep feed grinding regimes utilizing the benefits of high wheel speeds at large depths of cut and feed rates to achieve high stock removal rates. Described by Tawakoli (1993), the process readily achieves specific stock removal rates in excess of 50mm^3/mm·s. whilst improving tool wear, specific energy requirement and surface integrity.

Tawakoli (1993) also highlights the low workpiece surface temperatures resulting from the HEDG process. The beneficial contact conditions, high angle of inclination and high wheel and workpiece speeds result in a low workpiece surface temperature and the temperature trend presented in figure 5. It is to be questioned whether the same profile would exist in the sidewall, where no benefit from an angle of inclination is to be found. Research in the field of High-performance profile grinding by Werner and Tawakoli (1988a), presents an example of the machine requirements for the HEDG process. The higher grinding forces described call for a machine exhibiting:

– a rigid machine bed;
– strong and powerful spindle drives and bearings;
– guide members of adequate dimensions;

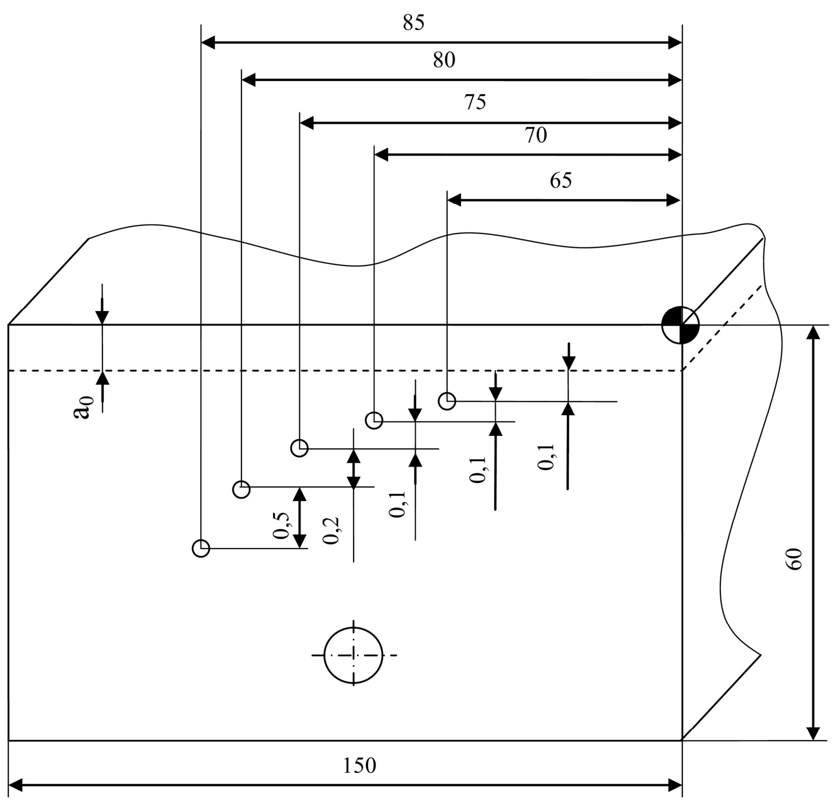

Fig. 4. Schematic of thermocouple technique for measurement of surface temperatures during grinding

– a good coolant supply and filtering system;

– suitable grinding wheels and dressing devices where applicable.

Further, wheel requirements are specified for high wheel speeds (greater than 125m/s), the high centrifugal forces requiring an electroplated steel wheel as the risk of wheel burst with conventional abrasives is too high. Rowe and Jin (2001) support the use of electroplated wheels describing the high wheel wear rate encountered during HEDG trials with an alumina wheel and calling for the future use of stronger wheels at higher wheel speeds.

The effect of the contact angle and the energy partitioning consistent with the HEDG regime. The result is a threshold line whose temperature fits with the results set witnessed in experimentation. However, the technique is limited to a single wheel speed and threshold lines would need recalculating whenever a change in wheel speed was undertaken:

– the use of cutting oils during grinding with the addition of the application of coolant to the wheel side to reduce net grinding power requirements;

– a thin width of cut or feed per turn to maximize available machine power;

– a very high workpiece speed to minimize temperature penetration in to the ground surface.

The conclusions drawn from the thesis leave a number of avenues for potential further work. These are centered on further validation of the new relationships drawn in the burn threshold diagram and an improved understanding of the energy partitioning with a full breakdown of the temperature at multiple points on the surface. The recommendations are therefore:

– extension into more complex geometries using the temperature measurement technique for analysis of turbine blade root forms for example;

– a breakdown of the temperatures at the workpiece surface with a wider selection of thermal coatings more suited to the high temperatures experienced in order to develop a full partitioning range around the profile.

Rowe and support the use of electroplated wheels describing the high wheel wear rate encountered during HEDG trials with an alumina wheel and calling for the future use of stronger wheels at higher wheel speeds

Conclusions

The basic mechanisms and the applications for the technology of high-efficiency grinding with CBN grinding wheels are presented. In addition to developments in process technology associated with high-speed and super-high grinding, quick point-grinding, high efficiency deep- cut grinding, creep feed deep grinding, heavy-duty snagging and abrasive belt grinding are also analyzed. The paper concludes with a presentation of current research and future developments in the area of high-efficiency grinding. The need for high accuracy finishing and for high efficiency machining of difficult-to-machine materials is making the application of abrasive technologies increasingly important. It is concluded that high efficiency abrasive machining is a promising technology in the future.

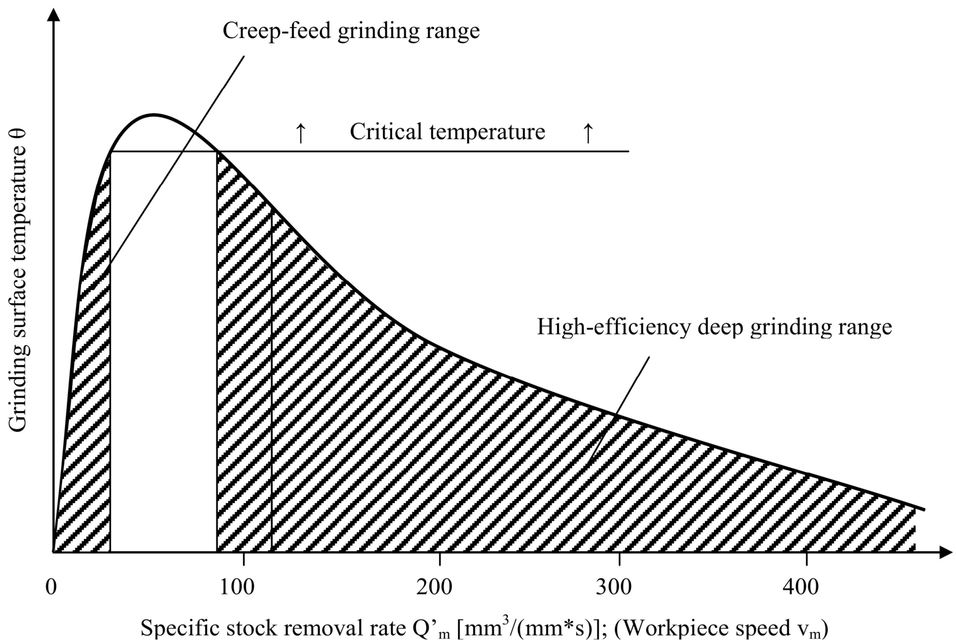

Fig. 5. Surface temperature trend in HEDG after Tawakoli (1993)

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ШЛІФУВАЛЬНІ ПРИЖОГИ У ПРОЦЕСІ ВИСОКОШВИДКІСНОГО ГЛИБИННОГО ШЛІФУВАННЯ

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Сформульовано проблему необхідності розробки нового обладнання та технології обробки методом глибинного шліфування плоских і плоско фасонних поверхонь деталей авіаційних двигунів з матеріалів, що важко оброблюються. Було проведено дослідження стану обладнання для глибинного шліфування. Отримано нове обладнання для обробки плоских і плоско фасонних поверхонь деталей авіаційних двигунів за допомогою планетарної шліфувальної головки, що дозволяє більш ефективно і з меншими трудовитратами вести обробку матеріалів, що важко оброблюються.

Ключові слова: глибинне шліфування, технологічний процес, планетарне глибинне шліфування, економічний ефект, матеріали, що важко оброблюються.

ШЛИФОВАЛЬНЫЕ ПРИЖОГИ В ПРОЦЕССЕ ВЫСОКОСКОРОСТНОГО ГЛУБИННОГО ШЛИФОВАНИЯ

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Сформулирована проблема необходимости разработки нового оборудования и технологии обработки методом глубинного шлифования плоских и плоско фасонных поверхностей деталей авиационных двигателей из труднообрабатываемых материалов. Было проведено исследование состояния применяемого оборудования для глубинного шлифования. Разработаны рекомендации по применению нового оборудования для обработки плоских и плоско фасонных поверхностей деталей авиационных двигателей при помощи различных видов шлифовальных кругов и смазываще-охлаждающих жидкостей, позволяющих более эффективно и с меньшими трудозатратами вести обработку труднообрабатываемых материалов.

Ключевые слова: глубинное шлифование, технологический процесс, планетарное глубинное шлифование, экономический эффект, труднообрабатываемые материалы.

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