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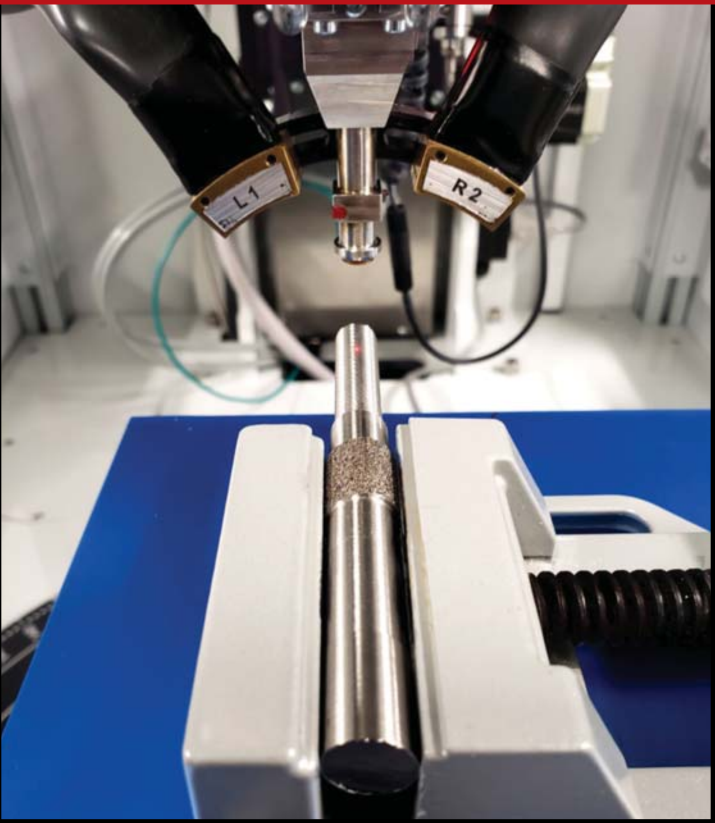

Influence of Abrasive Type on Grinding Induced Residual Stresses and Surface Integrity

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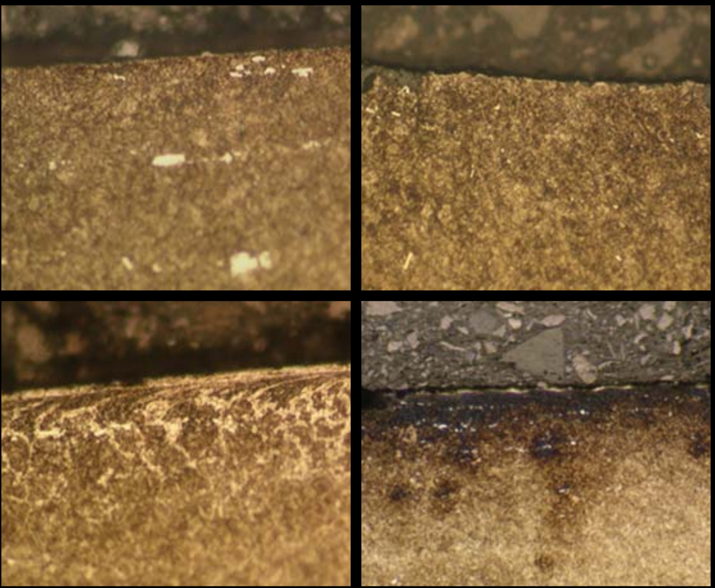

ABSTRACT

Many engineered products are subjected to applied cyclic and static stresses in their designed use. Examples include bearings, transmission shafts, and gas turbine blades/fans. In addition to these operational stresses, the materials often contain residual stresses, cracks, and defects, imparted during the manufacturing process, especially when high temperatures are created by chip formation and friction. Grinding is such a process, where surface and sub-surface damage can result if the process is not adequately controlled.

INTRODUCTION

The fatigue life of a metallic component that is subjected to cyclic stresses is significantly influenced by the surface and sub-surface condition produced by the manufacturing processes that made the component. As grinding is often the last process to be used to produce the final surface topography and surface integrity, manipulation of the thermal input and mechanical stresses is paramount. Tensile residual surface and sub-surface stresses created by grinding can add to the service stresses in use and lead to surface, or sub-surface cracking, plus tribological issues with bearing surfaces such as Brinelling, spalling, etc. Compressive residual stresses are deemed as desirable at a surface since they help the workpiece surface to resist the service stresses. The type of abrasive, grit size, sharpness of the wheel surface, wheelspeed, material removal rate, coolant delivery, etc, all affect the surface integrity of the final workpiece surface.

A schematic of a rotating stress fatigue tester is shown in Figure 2. The testpiece is continuously subjected to a once-perrev bending stress as it rotates, and a counter stops the revolution counter at the time of failure.

Aero-engine rotating components, wheel bearings, transmission shafts, etc, are categorized as critical components and are therefore subjected to highly stringent dimensional accuracy, surface integrity, and fatigue requirements. It is well documented that the functional performance of parts subjected to machining processes is strongly affected by the resulting material surface/subsurface integrity conditions [2]. Publications detailing investigations relating to the influence of material removal processes on workpiece residual stresses initially appeared in the 1950s, however, Field influence of material removal processes on workpiece residual stresses initially appeared in the 1950s, however, Field and Kahles [3] were the first to define the concept of surface integrity and propose associated methodologies for assessment, with particular application to machining processes.

Whilst specific standards of workpiece surface integrity and acceptance criteria for aero-engine components exist, they are commercially sensitive and closely guarded, which precludes full disclosure in the public domain. Nevertheless, surface integrity/metallurgical assessment of the workpiece following grinding is typically undertaken to confirm the absence of various anomalies including cracks, amorphous/recast layers, re-deposited/foreign material, contamination and work hardening, none of which would be acceptable. In addition, the analysis can also encompass residual stress measurement and cyclic life assessment. It is well known that the fatigue life of a cyclically loaded component is a function of its surface and sub-surface residual stress profile after machining.

Residual stress measurements are typically performed using two different approaches, X-Ray diffraction (for all metals) and Barkhausen Noise (just magnetic materials such as steel). X-Ray diffraction systems are considered to be destructive since after the surface stress is measured a layer of material is etched away and the process continued at the new surface. Barkhausen Noise systems use a dedicated sensor that conforms to the profile of the workpiece and after the measurement the workpiece can be ready for its' intended use. In addition, X-Ray diffraction gives the true stresses in the part, whereas Barkhausen Noise gives relative stresses and often uses a sample measured by X-Ray diffraction in order to calibrate the Barkhausen sensor output.

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Determining the Flowrate, Pressure and Nozzle Aperture for a Grinding Process with Consideration of Abrasive Type, Coolant Type and Wheel Structure

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Grinding is a thermally dominated process where many of the operational parameters such as feeds, speeds, wheel structure, dressing and abrasive type must consider the heat generated and how to remove it from the workpiece. Optimization of coolant application is a powerful tool to suppress thermal damage and allow greater control of the process setup parameters to create the required surface topography, integrity, productivity and size.

It is well known that matching the jet speed with the grinding wheel speed is an effective way to remove the boundary layer of air, and to wet the grinding process. Mathematical models based on energy equations, such as Bernoulli's, have previously been used to predict jet velocity, however, these are generally flawed as they don't consider the kinetic energy of the coolant entering the nozzle. They are also flawed because no consideration is made of the viscosity of the coolant, which is a dramatic effect. This paper presents a much more precise analysis of the flow from a nozzle and also considers nozzle efficiency. The paper also presents the flowrate requirements based on grinding power, abrasive type (superabrasives versus conventional abrasive) and the influence of wheel structure. The models are verified by accurate flow tests performed by the author.

Finally, a case study is presented that clearly shows the economic and technological advantages of coherent-jet nozzles over a more conventional approach.

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Introduction

Grinding is a complex chip removal process, which if done incorrectly can lead to surface damage to the work material, and unsatisfactory process economics due to inadequate removal rates and/or excessive wheel wear. The power consumed by the process is partitioned into the wheel, work, chip and coolant, and the amount that enters the workpiece must be cooled quickly to prevent high local temperatures and phase transformations from developing, and high remaining temperatures after the wheel has passed by. Phase transformations are often responsible for tensile residual stresses, white layer formation, reduced fatigue life, and surface and sub-surface cracking. Cooling of the process is achieved by the application of a cooling and lubricating fluid, as well as selecting process parameters that reduce the heat being generated.

In creep feed grinding, where the contact arc is long, the thermal input into the part is high, and the chips produced and abrasive lost from the wheel also need to be flushed away. This often results in the application of excessive flowrates in an attempt to maintain the quality and economics of the process. Such a grinding fluid application system requires a powerful pump, large settling and cooling reservoir, high worktable drain rate and an effective mist collector. The excessive heat produced by such a pump often requires refrigeration of the coolant to maintain a constant temperature throughout a production shift.

Many researchers have studied the role of grinding fluids in preventing thermal damage to the workpiece, including Brinksmeier [1]. Andrew [2] defined the critical power flux at 'burnout' to be approximately 30 W/mm2, in the contact area between an aluminum oxide grinding wheel and the workpiece during continuous dressing creep feed grinding (CDCF). Beyond this value the workpiece surface would experience a rapid boiling of the fluid in the grinding arc, resulting in literally a dry process with its associated high temperature. Guo [3] quoted a similar power flux value at similar grinding conditions and work material. Guo [4] also explained that when the workpiece surface temperature is below the boiling point of the fluid then a liquid phase will be present in the grinding arc. As the temperature of the fluid increases, the liquid will undergo nucleate boiling, which can enhance convective cooling. As the fluid temperature increases still further a vapour film will form which blankets the heated workpiece surface suppressing heat transfer. This film boiling threshold temperature is around 130°C (266°C) for a water-based fluid. As compared to the CDCF grinding critical power flux stated above, Rowe [5] obtained values over 200 W/mm2 , for HEDG grinding with CBN grinding wheels, in oil coolant, at 10 times the material removal rate of Andrew [2], which can be partly explained by Rowe's smaller contact length, much higher work speed and higher wheel-speed.