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Analysis of Non-Conventional Machining Process on ADI

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ABSTRACT

Machining is one of the major contributors to the high cost of titanium-based components. This is as a result of severe tool wear and high volume of waste generated from the workpiece. Research efforts seeking to reduce the cost of titanium alloys have explored the possibility of either eliminating machining as a processing step or optimising parameters for machining titanium alloys. Since the former is still at the infant stage, this article provides a review on the common machining techniques that were used for processing titanium-based components. These techniques are classified into two major categories based on the type of contact between the titanium workpiece and the tool. The two categories were dubbed conventional and non-conventional machining techniques. Most of the parameters that are associated with these techniques and their corresponding machinability indicators were presented. The common machinability indicators that are covered in this review include surface roughness, cutting forces, tool wear rate, chip formation and material removal rate. However, surface roughness, tool wear rate and metal removal rate were emphasised. The critical or optimum combination of parameters for achieving improved machinability was also highlighted. Some recommendations on future research directions are made.

INTRODUCTION

Despite the attractive combination of properties that has seen titanium and its variants transcend predominantly from the aerospace and military applications in the 1950s to other niche applications − automotive, chemical, and biomedical − as we have today, the challenge of difficult machining is still persistent [1,2]. Hence, the long coveted widespread use of titanium-based alloys remains far from being realised. The attributes of titanium and its alloys which include low thermal conductivity, low elastic modulus, high chemical reactivity and high temperature strength qualify titanium-based alloys as difficult-to-machine material [3,4]. In fact, titanium and nickel-based alloys are considered the most difficult-to-machine structural materials used in engineering applications [5]. The poor thermal conductivity of titanium and its variants, the heat generated at the interface between the tool and workpiece and low volumetric heat capacity of titanium and its alloys retard dissipation of heat to the surrounding. So, about 80% of the heat generated at the interface is conducted by the tool, hence causing rapid tool wear [6–9]. The low elastic modulus of titanium alloys leads to high spring back which causes vibrations during machining and ultimately results in poor surface finish [8,10]. This poor surface finish is not desirable in machined titanium workpiece as they may contain stress raisers like cracks [3,4] which would initiate fatigue failure under in-service conditions. The difficulty experienced during machining of titanium-based alloys varies with alloy chemistry, machining techniques, design and geometry of cutting tools and components, to mention a few.

A corollary to difficult machining of titanium-based alloys is high cost of manufacturing. Machining remains the most significant factor contributing to the high cost of titanium and its alloys. The process accounts for 40% of the total cost of manufacturing titanium-based components. Additionally, nearly 95% of bulk titanium material is machined away as swarf when manufacturing some aerospace grade components. To fully take advantage of the high specific strength, excellent corrosion resistance and excellent biocompatibility of titanium-based alloys when making highly efficient automotive engines and affordable biomedical implants for orthopedic treatments, the challenges posed by machining during processing of titanium-based components must be resolved.

Research efforts seeking to solve this problem have explored two major approaches. The first approach is a more recent one and it involves developing processing routes that minimize or exclude machining as one of the processing steps. Notable examples are conventional powder metallurgy or additive manufacturing processes for producing near-net shaped components. The major disadvantage these techniques have is that large and complex shaped components are not be easily manufactured. Other examples of the first approach are advanced solid-state processes like FAST-forge and FAST-DB processes . These processes have been used to produce near-net shaped profiles with comparable properties to wrought alloys produced from conventional processing routes. In the FAST-forge process, titanium powder or swarf is consolidated using a combination of field assisted sintering technology (FAST) and a one-step precision hot forging, to produce a near-net shaped profile. FAST-DB is a process of developing functionally graded near-net shaped components by consolidating powders of dissimilar metals or alloys using FAST-forge process. The functionally graded components are produced as a result of diffusion bonding (DB) between the dissimilar powders. Since these advanced techniques are still at the infant stage and still requires lots of research efforts to fully become a commercially viable process, the available literatures on this approach are limited and are not considered beyond this point in this review.

In this paper, we have identified different machining techniques and group them into conventional and non-conventional techniques based on the contact between the tool and the workpiece. Each category of machining techniques has several review articles which has helped readers to keep up with the recent advances in titanium machining, but to the best of the authors' knowledge, a single review article which covers both conventional and non-conventional machining techniques is rarely available. Hence, we attempt to provide a succinct review which captures the prominent machining techniques for titanium processing. The authors believe that this review will be of great benefit to researchers who are just developing new interest in titanium machining as it gives a succinct account of the different machining techniques, the important machining parameters and key machinability indicators.

Machining Techniques

There is an increase in the demand for titanium alloys especially in the aerospace industries In aerospace industries, titanium alloys are not only used for making fan blades, landing gear and other engine parts, but also for making fasteners for new lightweight carbon fiber fuselage and wings. An example is the transition to carbon fiber fuselage and wings in Airbus A380-800, a major change from the materials selected for Airbus A340 The choice of using titanium alloys particularly for carbon fibre fuselage fasteners is informed by its superior compatibility with carbon in comparison to aluminum alloys . Also, increase in bone fractures in the ageing population has increased the demand for affordable titanium-based implants and medical devices for orthopedic and dental treatments . Consequently, a wide range of machining techniques are now being explored to increase production of titanium parts. These techniques are discussed under the broad topics of conventional machining and non-conventional machining.

Conventional Machining

The major signature of conventional machining is that there is direct contact between the cutting tool and the workpiece. As shown in Supplementary Table S1, the different machining operations under this category include turning, milling and drilling which are performed under dry or wet conditions These operations have other variants such as micro milling, face milling, planar milling, angular milling, horizontal drilling, directional drilling, ultra-precision machining to mention a few . Table S1 suggests that Ti-6Al-4V was mostly investigated and the different cutting parameters that were considered are equally listed. The parameters for these operations are similar but machining conditions are not the same. Researchers had often investigated the influence of parameters such as depth of cut, spindle speed, spindle power, cutting material, cutting speed, feed rate on machinability indicators such as the tool wear rate, chip formation and surface roughness of the workpiece. The disparities in machining conditions make it difficult to compare results.

LITERATURE REVIEW

Austempering of ductile irons produce a unique material with outstanding properties of high strength and good ductility. Austempered ductile iron (ADI) is twice as strong as standard ductile iron grades with comparable toughness. Apart from these, it is responsive to work hardening surface treatments and posses excellent fatigue and wear properties. Compared to forged steel components ADI offers high strength-to-weight ratio, lower production costs of near net shape castings, and good machinability. The austempering treatment involves following steps: Subsequent cooling to room temperature after predetermined austempering time.

Carbon: Variation of total carbon in a narrow range (~3.6%) will have little effect on the properties of austempered iron. Since equilibrium carbon content in the austenite phase will not be affected much, the IT characteristics will not be changed.

Silicon: Silicon is a graphitizing element and decreases the solubility of carbon in austenite. It raises the eutectoid temperature and inhibits the formation of bainitic carbide. Increasing the silicon content increases the impact energy of the ADI and lowers the ductile–brittle transition temperature. The Si content should be restricted to 2.4–2.8%.

Manganese: Mn is an element which has a strong effect on hardenability but it has a tendency to segregate at cell boundaries and retards the austempering transformation by forming carbides. This segregating tendency is particularly prominent in the castings with lower nodule counts or thick section castings (>20 mm). The high segregation of Mn causes shrinkage, carbides, and unstable austenite. The ultimate effect is deterioration of mechanical properties and poor machinability. In view of this, the Mn content is restricted in austemepered ductile iron to less than 0.3%.

Copper: Copper is also effective in increasing the hardenablity. However, it has no significant on tensile strength but improves ductility when austempered at a temperature below 350 °C.

Nickel: Nickel is also effective in increasing the hardenability but at lower austempering temperature below 350 °C. Nickel has a tendency to decrease the tensile strength but increases the ductility and fracture toughness. Nickel content is restricted to 2% in ADIs.

Molybdenum: It is a very potent element to increase the hardenability (Figure 33) and is invariably necessary for heavy section castings to prevent pearlite formation. Like Mn it also has a segregating tendency at cell boundaries and forms carbides. As a result, both tensile strength and ductility decrease with increase in Mo content. Therefore, Mo content is restricted to 0.2% in heavy section castings with an objective to improve the hardenability.

Effect of metallurgical variables on the properties of ADI

The selection of composition for both ductile iron as well as ADI is important. Firstly, the elements which adversely affect the spheroid formation or carbide and inclusion formation or propmotion of shrinkage should be restricted. Secondly, control should be exercised to the elements which affect hardenability and the properties of transformed microstructure.

The section size of components, the type of quenching media and the severity of quench are determining factors for the optimum alloying requirements.[6]

In an agitated molten salt bath quench, section sizes up to about 10 mm of an unalloyed ductile iron can be successfully through hardened without the formation of pearlite. In an agitated austempering bath with water saturation, section sizes up to about 20 mm can be through hardened for unalloyed iron. Proper alloying is needed to through harden and to avoid pearlite formation in the microstructure. Followings are the effects of carbon, silicon, and other alloying elements like manganese, copper, nickel, and molybdenum.

METHODOLOGY

Electric Discharge Machining Electric Discharge Machining (EDM) is an electro-thermal non-conventional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs International Journal of Engineering Research & Technology (IJERT) Vol. 1 Issue 3, May - 2012 ISSN: 2278-0181 www.ijert.org 2 3 due to thermal energy of the spark. EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. EDM can be used to machine difficult geometries in small batches or even on job-shop basis.

Work material to be machined by EDM has to be electrically conductive.

Electrochemical Machining (ECM) ECM is opposite of electrochemical or galvanic coating or deposition process. Thus ECM can be thought of a controlled anodic dissolution at atomic level of the work piece that is electrically conductive by a shaped tool due to flow of high current at relatively low potential difference through an electrolyte which is quite often water based neutral salt solution. During ECM, there will be reactions occurring at the electrodes i.e. at the anode or work piece and at the cathode or the tool within the electrolyte. MRR is an important characteristic to evaluate efficiency of a non-traditional machining process. In ECM, material removal takes place due to atomic dissolution of work material.

Abrasive Water Jet Machining (AWJM) In the abrasive water jet, the water jet stream accelerates abrasive particles and those particles erode the material. In AWJM, abrasive particles like sand (SiO2), glass beads are added to the water jet to enhance its cutting ability by many folds. In AWJM, the abrasive particles are allowed to entrain in water jet to form abrasive water jet with sig

Comparison of non-conventional machining processes

"Muller and Monaghan (2000) present details and results of an investigation into the machinability of SiC particle reinforced aluminum matrix composites using non-conventional machining processes such as EDM, laser cutting and AWJM. The surface integrity of the composite material for these different machining processes are examined and compared. The influence of the ceramic particle reinforcement on the machining process was analyzed". "Muller and Monaghan (2001) investigated into the machinability of silicon carbide particle reinforced aluminum alloy matrix composites using non-conventional machining processes such as EDM and laser cutting. The different removal mechanisms of the different processes when machining the composite were investigated. The surface condition and sub-surface damage of the material for the different machining processes have been examined and compared. It appears that both EDM and laser are suitable processes for machining AMMCs, Laser offers significant advantages in terms of removal rate. EDM however induce less thermal damage than that was observed using the laser. Liu et al. (2009) studied the behavior of wire electrochemical discharge machining of Al2O3 article reinforced aluminum alloy 6061. The relative strength of the WEDM and ECM activities in the machining process under different conditions was investigated with the aid of the voltage waveforms. In this paper, authors compared two types of machining processes with same material. Only material removal rate is considered as performance measures.

CONCLUSION

A review of the research work on AMMCs with non-conventional machining is presented in this paper. The research work of the last 20 years has been discussed. Of the many of non-traditional machining methods reviewed in this article, EDM is currently used extensively in industry for machining of AMMCs. This is reflected in the number of publications concerned with these processes. For each and every method introduced and employed in machining proce ss, the objectives are the same: to enhance the capability of machining performance i.e. more material removal rate and better surface finish and to get better output product.

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